

1987/1988

ANNUAL PROGRAM REPORT

APIOS

ACID PRECIPITATION IN ONTARIO STUDY
ONTARIO MINISTRY OF THE ENVIRONMENT
PROGRAM COORDINATOR: G.W. SCOTT
APIOS REPORT 012-88

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INTRODUCTION

In 1979, Ontario established the **Acidic Precipitation in Ontario Study (APIOS)** to investigate the causes and effects of the long-range transport of air pollutants.

A. SCIENCE

The program is organized into seven work groups:

1. emissions and atmospheric processes,
2. aquatic effects,
3. terrestrial effects,
4. biogeochemical effects,
5. legal initiatives,
6. environmental management and economics, and
7. communications.

Each program area has its own specific goals and obtains its direction from an interbranch or interministerial Working Group. In addition, the credibility of the scientific research is assured by a documented and operational quality assurance program.

The APIOS program does not have a health effects or materials damage component because these are being addressed by small federal specialist groups on a Canada-wide basis. The APIOS Office endeavours to keep abreast of development in these two areas and ensures the provision of APIOS technical support when needed (e.g. deposition data).

Ontario's research and emission control efforts are coordinated with

other parts of Canada and the United States since the solution to the LRTAP problem requires action by all jurisdictions involved. Appendix I provides a summary of international LRTAP projects with MOE involvement. Appendix II provides a bibliography of APIOS related publications and technical reports.

B. ABATEMENT

Since 1980, Ontario has believed that there was sufficient evidence to implement SO₂ controls immediately while research continued to evaluate the benefits of these controls. As a result, Ontario was the first jurisdiction in North America to mandate emission controls based solely on the effects of long-range transport of air pollutants, as distinct from local ambient air quality standards. Ontario Hydro and Inco were the targets of these controls.

In the absence of an acid rain agreement with the United States, the eastern Canadian provinces and the federal government decided in March 1984, to take unilateral action and reduce their sulphur dioxide emissions to a ceiling of 2.3 million tonnes by 1994, a 50% reduction from the 1980 base case year. On February 5, 1985, they agreed to the series of steps to achieve the first 1.9 million tonnes of this reduction and committed to determining the allocation of any further reductions in sufficient time to achieve the 1994 objective.

Subsequently, Ontario went beyond the commitment it made at the federal/provincial meetings with its Countdown Acid Rain program. This program was announced in December 1985. It will reduce sulphur dioxide emissions from the 1980 base case level of 2,194 kilotonnes to 885 kilotonnes by 1994.

The four non-appealable regulations apply to the four corporate sources which together emit 80% of Ontario's SO₂: Inco, Falconbridge, Algoma Steel (Wawa) and Ontario Hydro. The regulated annual emission limits were developed in consultation with each of the major pollution sources to ensure that economic activity need not be excessively inhibited.

Control technologies are not specified and the individual companies may choose their method of abatement. The regulations only require that the legal limits are met by the specified dates. The regulations provide for a three year research and development period, leading up to a final report by December 31, 1988 from each of the major sources. This report will spell out precisely how the emission limits will be met. The semi-annual interim progress reports, provided by the four major companies as required under the regulation, are reviewed by experts from various Ontario ministries. The government's summary and analysis of these reports along with copies of the company reports are widely circulated.

Countdown Acid Rain will do more than just help Ontario's environment; it will also reduce acid rain in Quebec and the northeastern United States. However, the major emission reductions in Ontario and elsewhere in eastern Canada will not be sufficient to achieve the 20 kilogram per hectare wet sulphate deposition target which will protect some aquatic ecosystems. Major emission reductions are also required in the United States.

All Canadian attempts to negotiate a bilateral treaty on acid rain with the United States have failed to date. While President Reagan has reaffirmed his commitment to clean coal technology development and agreed to consider the possibility of an accord, there has been no progress.

C. PUBLIC INFORMATION EXCHANGE

Ontario citizens are aware of acid rain and are educating themselves as evidenced by the number of information requests made directly to the APIOS Coordination Office. Over 650 individualized packages of information were mailed in this fiscal year and 400 people visited the Office. These contacts are over and above the enormous quantity of requests for acid rain information and the fish poster handled directly by the Communications Branch.

It is hoped that Ontario's realistic and practical approach in severely limiting its own emissions will encourage the United States to take similar positive action.

LEGAL INITIATIVES

INTERNATIONAL INITIATIVES

Under the Memorandum of Intent signed in 1980, Canada and the United States agreed to enforce existing laws and regulations in a way which is responsive to the problems of transboundary air pollution. Since 1981, however, the United States Environmental Protection Agency proposed the approval of revisions in State Implementation Plans (S.I.P.'s) under Section 110 of the U.S. Clean Air Act which would lead to increases in allowable sulphur dioxide emissions from coal-fired power plants. Since increased emissions could affect the province's environmental quality, Ontario encouraged the U.S. EPA Administrator and state governments to disapprove any S.I.P. revisions which would result in any increase in permissible emissions of SO₂ in the U.S.

In June 1981, Ontario appeared at the U.S. EPA Section 126 Hearings held in Washington, D.C. in support of the States of New York, Pennsylvania and Maine in their petition concerning Interstate Pollution (Section 126 Clean Air Act). This Section provides for the intervention of the Administrator of the U.S. EPA in instances when interstate air pollution can be shown to be preventing the attainment of national ambient air quality standards, or interfering with those prevention of significant deterioration or visibility measures which the Act requires to be

included as a part of a state implementation plan. New York and Pennsylvania maintained that SO₂ and particulate sources in the Midwest (Ohio, West Virginia, Illinois, Indiana, Michigan, Ohio, Tennessee and Kentucky) were in fact preventing attainment. Maine subsequently consolidated a similar petition with New York and Pennsylvania.

In March 1984, the States of New York, Maine, Vermont, Rhode Island, Connecticut and Massachusetts, together with several environmental groups and United States citizens filed a legal suit against the U.S. EPA that:

- i) the Administrator has violated his mandatory duty under Section 126 to issue a final decision on the petitions regarding interstate air pollution by the deadline (within sixty days) specified in the statute and
- ii) that the Administrator has violated his mandatory duty to determine which states are contributing to air pollution which endangers the public health and welfare of Canada and to give notice to the Governors of such States to revise the State Implementation Plans in order to prevent or eliminate harm.

In December 1984, the U.S. EPA Administrator denied the Section 126 petitions having determined that

while pollution does cross state lines into petitioning states, the petitioning states did not adequately support their claims of injury. This decision was appealed to the U.S. Circuit Court of Appeals.

reaffirm and promulgate the endangerment findings which had been accepted in the previous court actions by publishing the findings in the Federal Register and then promulgate the findings in final rules.

In July 1985, the U.S. federal judge Norma Holloway Johnson ordered the U.S. Environmental Protection Agency to set in motion the necessary processes to reduce acid rain emissions in states where emissions originate. The EPA appealed, saying the court-imposed deadline was "inadequate". The judge decided, on September 24, 1985, to uphold her decision on a nine-month delay, requiring EPA to set in motion steps leading to a reduction in emissions causing acid rain. The same day, EPA appealed the court judgement. The agency questioned the role of the courts and the adequacy of programs directed by judicial order in the acid rain issue. Ontario obtained party status and filed a brief.

In May 1986, U.S. District Court heard arguments from both sides and reserved judgement. In September 1986, the U.S. Court of Appeals for the District of Columbia Circuit rendered its decision to reverse and remand the order to District Court with instructions to dismiss. Ontario jointly petitioned, with the State of Maine, for a re-hearing of the case and was turned down within two weeks.

In February 1987, Ontario and New York filed independent petitions to the U.S. Supreme Court to review the entire case, using writ of certiorari.

In June 1987, the Supreme Court rejected the appeal and let stand an Appeal Court (September 1986) ruling that dismissed the suit.

In April 1988, Ontario and a group of states filed independent petitions to the U.S. EPA administrator requesting that he

ATMOSPHERIC PROCESSES STUDIES

A. EMISSIONS INVENTORY

The compilation of statistics on the production of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and other pollutants serves several purposes:

- trends in emissions of acid-producing gases are determined and matched with changes in deposition patterns;
- detailed information on SO_2 and NO_x emissions by geographic location is required by all of the atmospheric models;
- knowledge of the location and magnitude of emission sources is also essential in planning cutbacks of acid gas emissions.

The Ontario Acid Rain Emission Inventory was upgraded during FY 1987/88 to provide more complete information regarding SO_2 , NO_x and VOC (volatile organic compound) emissions as well as related statistics. A detailed Ontario emission inventory for the base year 1985 was finished. Alkaline dust and ammonia emissions information was compiled to be used as input to long-range transport models.

A common emission estimation methodology for NO_x was established together with Environment Canada. Trend analysis of the preliminary 1986 and 1987

Ontario SO_2 data has indicated that there is a slight increase of SO_2 from 1983. This trend reflects the general economic recovery in the province since 1983. Overall, there was a decrease in SO_2 emissions from 1980 to 1987 of about 20%, from 1.8 million tonnes to 1.4 million tonnes. For NO_x , there has been a slight increase in Ontario emissions since 1980.

Figures 1 and 2 show the trends in Ontario's sulphur dioxide and nitrogen oxide emissions from 1971-1985.

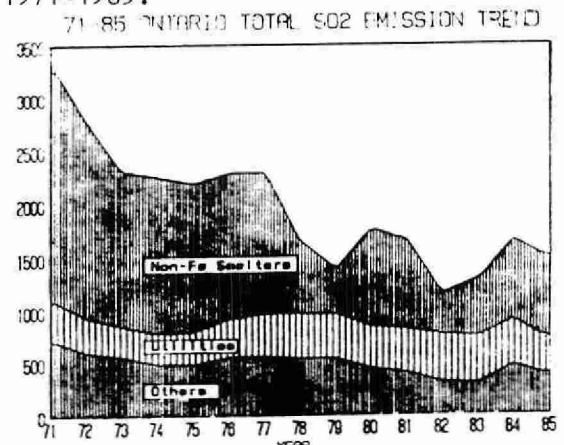


Figure 1: 71-85 Ontario total SO_2 emission trend.

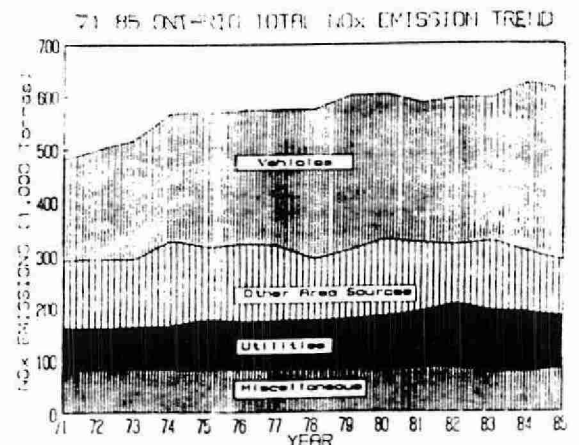


Figure 2: 71-85 Ontario total NO_x emission trend.

B. MODELLING STUDIES

Mathematical models combine our knowledge of the movement of air masses and the scavenging and chemical transformation of pollutants during transport into a set of numerical equations. Output from the models can be compared to observed deposition patterns, and if the comparison shows a close agreement, we gain confidence that we have a good understanding of the causes and mechanisms involved in acid deposition. Once the models are sufficiently developed, emission reduction scenarios can be assessed by looking at resulting deposition patterns. The models can also be used for interpretation of data.

The Acid Deposition and Oxidant Eulerian Model (ADOM) was evaluated for 20 days in April, 1981, coincident with the OSCAR field study (Oxidation and Scavenging Characteristics of April Rain). There were also several sensitivity tests using the model. The results can be summarized as follows.

Based on this limited evaluation the model predictions of the concentration of SO_4 (sulphate) in precipitation are mostly within a factor or two of the observations. A slight underprediction of the model could result from errors in emission inventories or differences between spatially averaged model predictions compared to station (point) measurements.

The sensitivity of the model to initial conditions depends on meteorology and on the distribution and strength of the emission sources. The effect of initial conditions on air concentrations of secondary pollutants such as SO_4 is perceptible for up to four days, whereas air concentrations of SO_2 and concentrations of SO_4 in precipitation are not significantly affected beyond 48 hours in the main SO_2 source regions.

The model does not show a major sensitivity to the NH_3 (ammonia) emission inventory in the prediction of concentration of SO_4 in precipitation. A factor of seven increase in NH_3 emissions specified by the NAPAP 5.2 inventory increased the concentration of SO_4 in precipitation by an average of about ten percent, though daily individual values can vary between zero outside the heavy emissions area to slightly over 100% near the heavy emissions area.

The model shows the non-linear relationship between SO_x and NO_x emissions and the reduction of SO_4 and NO_3 (nitrate) concentrations in precipitation. For instance, when SO_2 emissions are reduced by 50% uniformly across the grid domain, the reduction in SO_4 concentration in precipitation is determined to be between 35 - 40% in most areas away from the influence of the grid boundaries (Fig. 3). The air concentrations of SO_4 show a reduction of more than 40% while SO_2 air concentrations are reduced nearly 50%. When SO_x and NO_x emissions are reduced simultaneously by 50% (uniformly over the grid) the concentration of SO_4 in precipitation is reduced by 30 - 35% whereas the concentration of NO_3 in precipitation is reduced by 50 - 60%.

The above results are attributed to the role and availability of oxidants such as H_2O_2 (hydrogen peroxide) and O_3 (ozone) in converting SO_2 to SO_4 in the aqueous phase and NO_x to NO_3 in the gas phase. A sensitivity study showed that between 50 - 80% of the SO_4 concentration in precipitation can be attributed to aqueous conversion of SO_2 . The reaction involving H_2O_2 in converting SO_2 to SO_4 in the aqueous phase can be comparable to oxidation by O_3 depending on meteorological conditions, although in general the H_2O_2 pathway was more important.

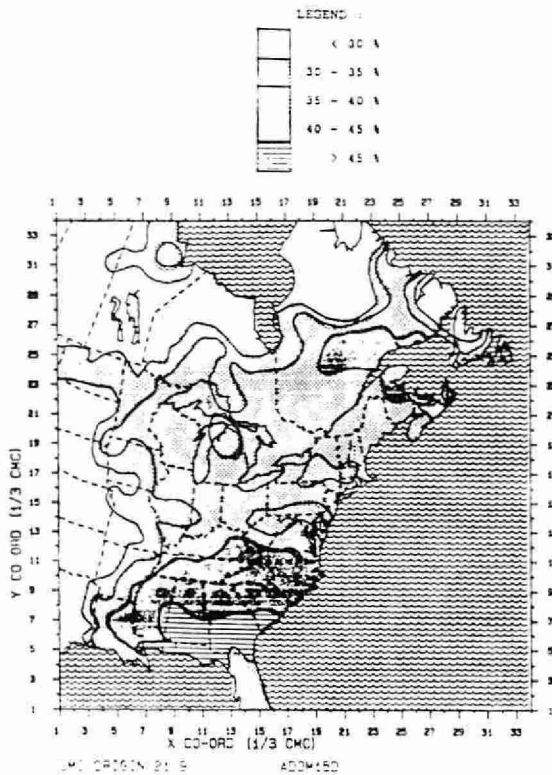


Figure 3: Percent change in wet concentration of SO_4 for a uniform reduction of SO_2 emissions by 50% over the grid domain. The results are for the period April 10-29, 1981.

These model results were compared with results from the Lagrangian model which uses simplified linear chemistry. When the 20 day integrated sulphate deposition results are compared, the models produced similar deposition patterns. However, the Lagrangian model, being a linear model, of necessity predicts a 50% reduction in SO_4 concentration in precipitation for a 50% reduction in SO_2 emissions.

The Eulerian model will be evaluated in the next two years with the data obtained in the joint U.S. and Canada field study project. The study is expected to provide detailed information on many chemical species which the model uses as input and generates as output. Other Eulerian modelling projects continuing in 1988 are evaluation of the model with tracer

data from the ANATEX experiment, as well as model evaluation for a winter episode and a high ozone summer episode.

The question of producing seasonal or annual wet deposition from a limited number of Eulerian model episode runs has also been addressed. The accuracy of extrapolated seasonal depositions from a given set of episode runs varied from receptor to receptor. The major factor affecting the accuracy of the predictions was the percentage of the season's precipitation at a site which was included in the sample days.

C. DEPOSITION MONITORING NETWORKS

Deposition monitoring has continued across the province in both the daily and 28 day networks. The daily network has been augmented to meet the requirements of the Eulerian Model Evaluation Field Study (EMEFS). Thus, four new sites have been added, with daily air measured at two sites where it had not been previously measured. Also, air chemistry will be measured intensively at Dorset (in concert with similar measurements collected by Environment Canada at their Egbert and Borden sites, as well as on board two aircraft). These measurements include formaldehyde and hydrogen peroxide (using a tunable diode laser absorption spectrophotometer), hydrocarbons (by gas chromatography), ozone and nitrogen oxides (using the highly-sensitive luminol method), and will last for approximately two months at a time during each of the seasons. The field study itself is scheduled to last for two years, and is conducted in co-operation with Environment Canada, the U.S. EPA, and the Electric Power Research Institute.

In the past year, routine QA and QC data were analysed and reported,

and there was an external audit of the network. Including network data for 1986, the period of record of reported data is now almost seven years. Figures 4 and 5 summarize the temporal patterns of SO_4 and NO_3 concentration as measured at the Dorset site.

Trace metal sampling in both air and precipitation has continued. These data will be analysed by several groups, including scientists outside MOE, to assist in source apportionments.

Aspects of the work of the deposition monitoring group were described at several international conferences and meetings during 1987.

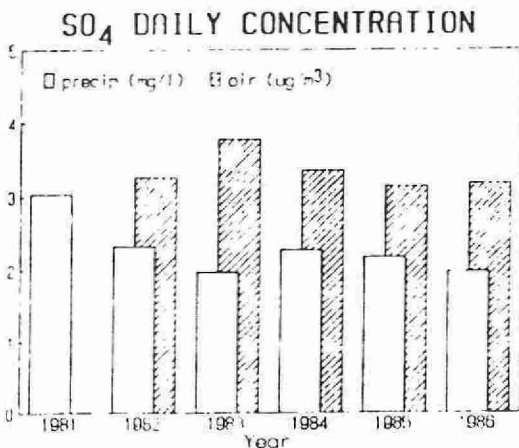


Figure 4: SO_4 daily concentration at the Dorset site.

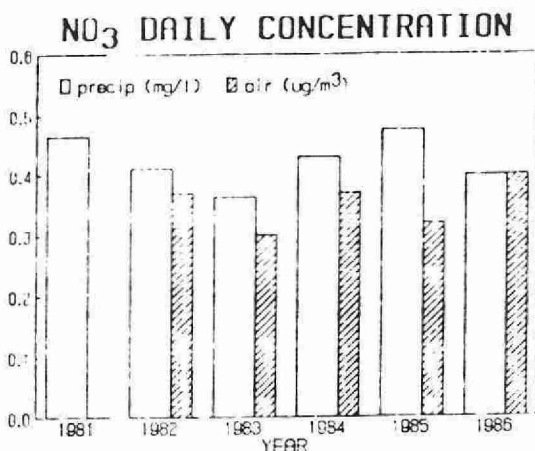


Figure 5: NO_3 daily concentration at the Dorset site.

D. OXIDANTS STRATEGY DEVELOPMENT

The development of an oxidants control strategy for Ontario, included the following work:

1. To determine if hydrocarbon or nitrogen oxide emissions should be controlled in order to lower the oxidant levels in southern Ontario. Work done with the EPA Regional Oxidants Model suggests that in the southern Ontario setting, NO_x rather than hydrocarbon emission controls may be more effective in lowering rural oxidant levels. Results from modelling at the Air Resources Branch using some monitoring data from the 1984 Sarnia Oxidants Study as the model input, support the above conclusions. Presently emission control scenario runs using the Acid Deposition and Oxidants model also examine the effect of regional hydrocarbon versus NO_x controls on oxidant levels in southern Ontario.
2. An assessment of the cost of hydrocarbon and NO_x emission controls in Ontario. Attention is being limited to the petrochemical, refinery and utilities sectors in two geographical areas - the Hamilton-Toronto-Oshawa corridor, and the Sarnia area.
3. An updated assessment of the damage to crops and associated costs due to oxidants in Ontario. This is an update of the work reported in 1984 in the MOE report "Ozone Effects on Crops in Ontario and Related Monetary Values."

E • METEOROLOGICAL STUDIES

A meteorological data acquisition system (MDAS), capable of providing support for special studies and episode analysis, as well as modelling activities, has been implemented. MDAS is a computerized system which collects and stores meteorological data supplied by Environment Canada from the North American network of weather stations. Air parcel trajectories are also calculated by the system for interpreting event precipitation and other air quality data.

During FY 1987/88 meteorological data were acquired and archived on an on-going basis. Air parcel trajectories at various locations in Ontario and eastern North America were calculated and archived on a daily basis. As well, the daily synoptic weather patterns for various locations in Ontario were also categorized and archived. Climatological compilation of boundary-layer statistics, aerodynamic resistances during dry deposition, and residence time analyses during transport were also completed.

Additional programs were completed to merge MDAS meteorological data and the data from the Ontario air quality monitoring network so that the two types of data may be analysed together.

TERRESTRIAL EFFECTS STUDIES

The primary objective of the Terrestrial Effects program is to determine the impact (if any) of acidic precipitation and related pollutants on the terrestrial environment. The program is divided into several sub tasks: Vegetation, Soils, and Forest Productivity and Decline studies (responsibility of the Ministry of the Environment) and the wildlife sub task (responsibility of the Ministry of Natural Resources). All of these sub tasks include several component projects. A synopsis of the major component projects follows.

A. VEGETATION STUDIES

Mobile Rain Exclusion Canopies

A fully automated rain exclusion canopy (REC) located at the MOE Phytotoxicology Laboratory in Brampton is used to assess the impact of acidic deposition and ozone on commercially valuable forest trees. The system consists of three mobile greenhouse shelters which exclude ambient rainfall and apply simulated acid rain (SAR) treatments to test plants established in the field. All aspects of the set-up are controlled by a microcomputer and data acquisition system. Depending on the research objectives, ambient levels of gaseous pollutants (i.e. O₃, SO₂ and NO_x) can be reduced in the field plots via a filtering system and perforated polyethylene distribution tubes. Gaseous pollutants such as ozone can also be injected into the treatment plots.

The REC system is presently being used to study the effect of acidic deposition on sugar maples, white spruce and poplar. During the fall of 1985 and spring of 1986, sugar maple transplants from the Dorset area and nursery grown white spruce seedlings from the MNR Midhurst nursery were potted in mineral soil taken from a site near Dorset (the Leslie Frost Centre). The most vigorous individuals were used for experimentation under the REC system in the spring of 1987. Rooted cuttings of three clones of hybrid poplar were also planted under the REC system to provide shelter for the maples and serve as an additional species to monitor.

The trees were subjected to three different SAR treatments (pH 3.2, 4.3 and 5.6) at regular intervals. Non-destructive measurements on the seedlings include:

1. visible injury rating;
2. photosynthesis rates;
3. throughfall and soil leachate chemistry;
4. plant height, stem diameter, leaf number, leaf area.

Destructive sampling of selected seedlings will be made to investigate:

1. pigment content of leaf tissues;
2. internal changes in cell size and shape;
3. physical and chemical changes in roots and foliage;
4. mycorrhizae.

Preliminary results from these experiments are expected in FY 89/90.

Greenhouse Experiments

An indoor greenhouse experiment was conducted in 1987 to investigate the joint effect of simulated acid rain and gaseous pollutants on growth and physiology of potted sugar maple and white spruce seedlings. The seedlings were exposed to three SAR treatments (pH 3.2, 4.3 and 5.6) and ozone treatments which included one event per week where over a 7-hour period the ozone concentration reached a peak of 110 ppb. Photosynthetic rates and transpiration were measured and the results are currently being analysed. In addition, changes in content of plant pigments (including chlorophyll) are being investigated.

Vegetation Baseline Sampling

Experiments have been designed to investigate the effect of acidic deposition on foliage chemistry. In 1981 and 1982 foliage from native trees (maple, birch, ironwood, poplar, basswood, oak, beech, white pine, white spruce, and hemlock) were sampled at 12 locations (mainly provincial parks and Conservation Authority lands) across southern Ontario. The samples were analysed for a number of constituent elements in order to establish baseline concentrations for each species and site. In 1987 the same trees were sampled again using the same procedures. When the chemical analysis is completed the results will be compared to determine whether there were any changes over time. Changes will be interpreted in light of known patterns of acidic deposition sampling dates and site conditions over the period between samplings.

sampled across Ontario. A report containing the 1982-83 soil baseline data will be produced in FY 1988/89. In 1987 approximately 100 original sites were resampled. After the chemical analysis of these samples, the results will be compared with those of the earlier sample period to determine if changes are occurring in the soil chemistry and whether these changes can be related to acidic deposition.

Soil Sensitivity Mapping

In cooperation with the Lands Directorate of Environment Canada, the Ontario Ministry of the Environment prepared and released a report entitled "Assessment of aquatic and terrestrial acid precipitation sensitivities for Ontario". The report includes a 1:1,000,000 scale colour map of Ontario in two parts depicting areas of relative ecosystem sensitivity to acidic precipitation. The sensitivity is based on soil depth, soil chemistry (or surrogates) and bedrock lithology. From this compilation, 23% of Ontario is interpreted as non-sensitive, 18% is moderately sensitive while 31% is highly sensitive. The remainder is comprised of organic terrain which has not been rated in terms of potential to reduce acidity or sensitivity to acidic precipitation. As shown in the accompanying map (Fig. 6), most of the sensitive sites are located on the Canadian Shield. Areas of southern Ontario underlain by limestone are not considered to be sensitive.

B. SOIL STUDIES

Baseline Studies

This study was designed to document the effect of acidic deposition on soil chemistry. Since 1980, over 400 soil baseline sites have been

GENERALIZED POTENTIAL OF SOILS AND BEDROCK
TO REDUCE ACIDITY OF ACID PRECIPITATION

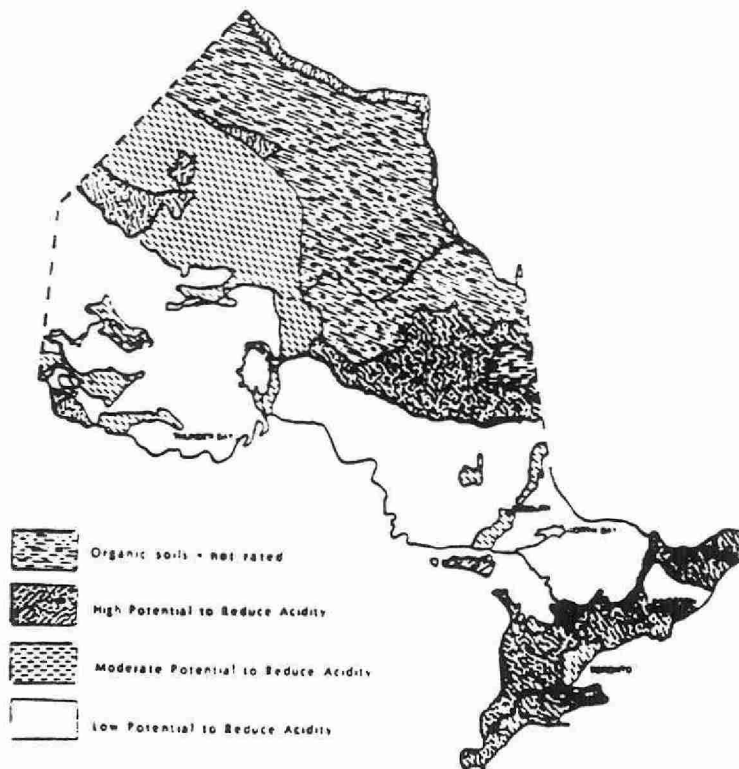


Figure 6: Generalized scheme of the potential of soils and bedrock to reduce acidity of acid precipitation.

C. FOREST PRODUCTIVITY AND
DECLINE STUDIES

Maple Decline Study

This study was initiated in 1984 to determine the role of acidic deposition in the decline of woodlots managed for maple syrup production in the Muskoka/Haliburton area of Ontario. Permanent observation plots were established to assess tree condition at seven locations. A control site at Thunder Bay was established in an area of low acidic deposition. In 1985, additional plots were added on calcareous soils near Peterborough and in an unmanaged stand in Algonquin Provincial Park. Tree condition has been assessed annually since the plots were established.

In general, the condition of the trees has remained the same or possibly has improved slightly over the study period (Table 1).

Determining the cause of tree dieback at each site is difficult owing to the many stresses that are or were in effect prior to the dieback. Severe defoliation by forest tent caterpillar in the late 1970's was combined with spring droughts in 1976, 1977 and 1983. *Armillaria mellea* root rot, tree age, site management, and possibly the additional stress of acidic deposition all may be responsible for the observed poor tree condition. Extremes in weather conditions also had a likely role to play. Causes of the dieback are summarized in Table 2.

Table 1: Annual Variation in Tree Condition Assessment* at the 11 Study Plots; 1984 to 1987

Plot	Mean Decline Index* (\pm SD)				LSD	P
	1984	1985	1986	1987		
Muskoka Mean	22.5(15.3)	20.9(14.1)	22.2(15.8)	18.3(17.2)	0.30	<.01
Peterborough Mean	NA	16.6(9.9)	14.2(8.5)	11.2(10.8)	0.56	<.01
Thunder Bay	18.6(11.1)	18.4(11.1)	27.6(7.8)	15.4(8.1)	1.47	<.01

* Decline index from 0 - 100, ranges are approximation:

0-15 healthy
16-30 moderate
> 30 severe

Table 2: Identification of Causal Factors of Sugar Maple Decline in Three Regions in Ontario. (Listed in decreasing order of significance in each column.)

Region	Causal Decline Factors		
	Inciting	Contributing	Predisposing
Thunder Bay	- climate stress (precipitation and thermal)	- tent caterpillar defoliation - Ca, K deficiencies	- tree age - wound frequency - northern location - possibly tree genetics
Muskoka	- tent caterpillar defoliation	- Armillariella mellea root rot fungus - stand management at 3 of 8 sites - climate stress (thermal) - soil acidification and Al toxicity (indirect effects of atmospheric pollutants)	- tree age - wound frequency - reduced tree vigor from the combined direct and indirect effects of atmospheric pollutants - possibly tree genetics
Peterborough	- climate stress (thermal)	- stand management at 1 of 2 sites - tent caterpillar defoliation	- tree age - wound frequency - reduced tree vigor from direct effects of atmospheric pollutants - possibly tree genetics

Forest Growth Study

Concern has been raised by studies in the United States and Europe that acidic deposition and other air pollutants may play a role in the reduction of tree growth rates. A tree growth study conducted with funding from APIOS by the Faculty of Forestry, University of Toronto is a continuation of a project that began in 1962 on forest growth in the Dorset area. The trees were remeasured in 1972, 1983 and 1984. This unique record allowed a detailed analysis of tree growth and stand dynamics and attempts to examine the effects of acidic deposition on these features. There was also a detailed statistical interpretation of competition among neighbouring trees. Detailed examination of the historical data showed that growth patterns at this location were highly variable and that any increased growth observed was not outside the ordinary growth rates over the past 90 years. A

final report for this project was submitted in May, 1987.

Dendrochronology Studies

The dendrochronology study of sugar maples was designed to determine whether growth decline is occurring across the province within three forest regions. Fifty-four plots have been sampled both destructively and by extracting increment cores. Data analysis using the Tree Ring Increment Measurement (TRIM) system has been completed. Fig. 7 shows a summary of the growth curves for each of the three forest sectors. The trees continued to grow until about 1960 when the growth rates started a general and rapid decline. This pattern is more or less consistent with that found in other regions of northeastern North America. The fact that the decline in growth rate is sustained even in these sample trees which had no conspicuous dieback is of major concern.

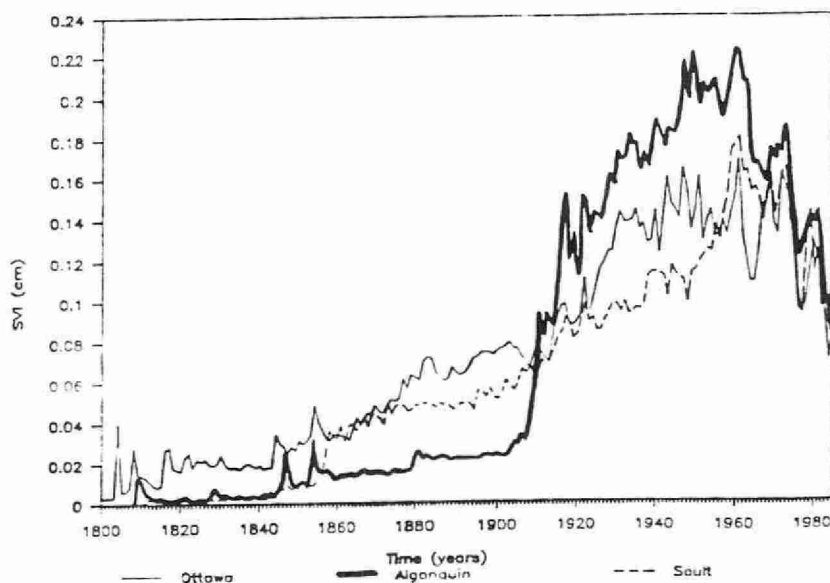


Figure 7: Mean specific volume increment of sugar maple from Ottawa, Algonquin and Sault Ste Marie.

Hardwood Decline Studies

In FY 1985/86 and FY 1986/87 a study was initiated to determine the incidence and severity of hardwood decline across the province. One hundred permanent observation plots dominated by sugar maple were established across the province. Each tree within the plot was assessed according to the amount of dead branches, chlorosis and undersized leaves in the crown. This data was used to calculate a decline index using 0 to represent a tree without any dieback, and 100 to represent a dead tree. The plots were all re-evaluated in the summer of 1987 (FY 87/88). Data from the original evaluation indicate the presence of plots with moderate to severe dieback in the southwestern part of the province as well as the Niagara and Muskoka areas. Dieback is scattered through the northern part of the study area while there is a broad band of relatively healthy hardwood stands extending from Lake Huron south of Georgian

Bay east to the Ottawa area. No pattern of dieback problems were seen that could be directly related to acidic deposition patterns; however, soil characteristics, particularly higher buffering potential of limestone-based soils, may have an important role in the distribution of the problem sites. The severity and extent of dieback was greatest where soil was most sensitive and deposition was highest. The distribution of dieback at the established plots is shown in Fig. 8.

Remote Sensing

Rapid assessment of the extent and severity of forest dieback relies on techniques with a remote sensing component. Such techniques are expensive and are still in the developmental stages. During the summer of 1988, funding was provided to apply a relatively inexpensive remote sensing approach to study sugar maple dieback. By combining light filters and a series of video

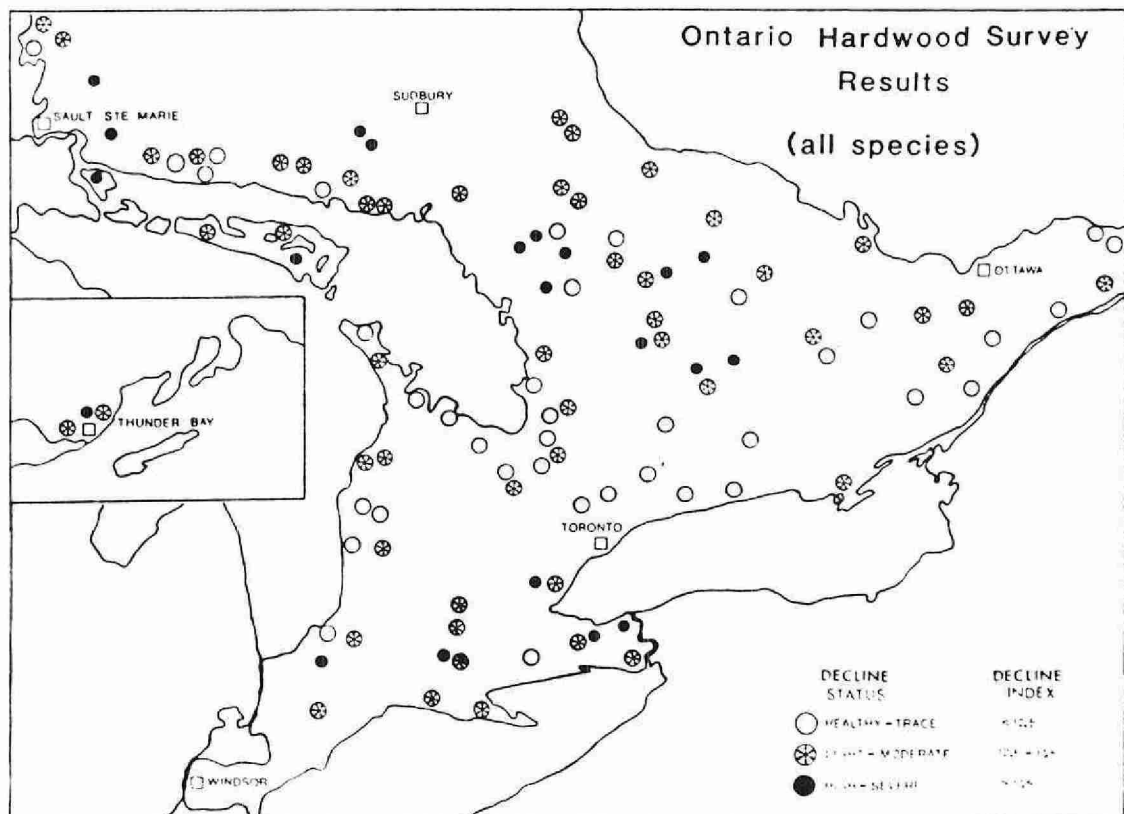


Figure 8: Distribution of dieback (based on the decline index) at established plots throughout Ontario.

cameras, it was possible to obtain photographic records of selected maple plots. The video tapes were digitally analysed using a computer. The method appears to be highly promising although additional work is required before it can be routinely applied.

Early Diagnosis of Forest Decline

In the summer of 1986, the Ontario Ministry of the Environment participated in a study in Europe intended to develop new methods of diagnosing forest dieback prior to the development of conspicuous symptoms on the trees. A comparable study was initiated in Ontario in 1987. Foliage samples of sugar

maple, white pine and Norway spruce (common denominator species with Europe) were collected at 16 locations across a pollution gradient from southwest to southeastern Ontario (Fig. 9). Some of the tests performed on the conifer foliage indicated a response to the pollution gradient. Contact angle measurements which are an indication of the condition of the cuticular layer of the needles suggested that the cuticle was abrading or being lost at a greater rate in the more polluted sites. Although there was a great deal of variability among sample sites, the procedure indicates that there are parallels between the Ontario and European conditions.

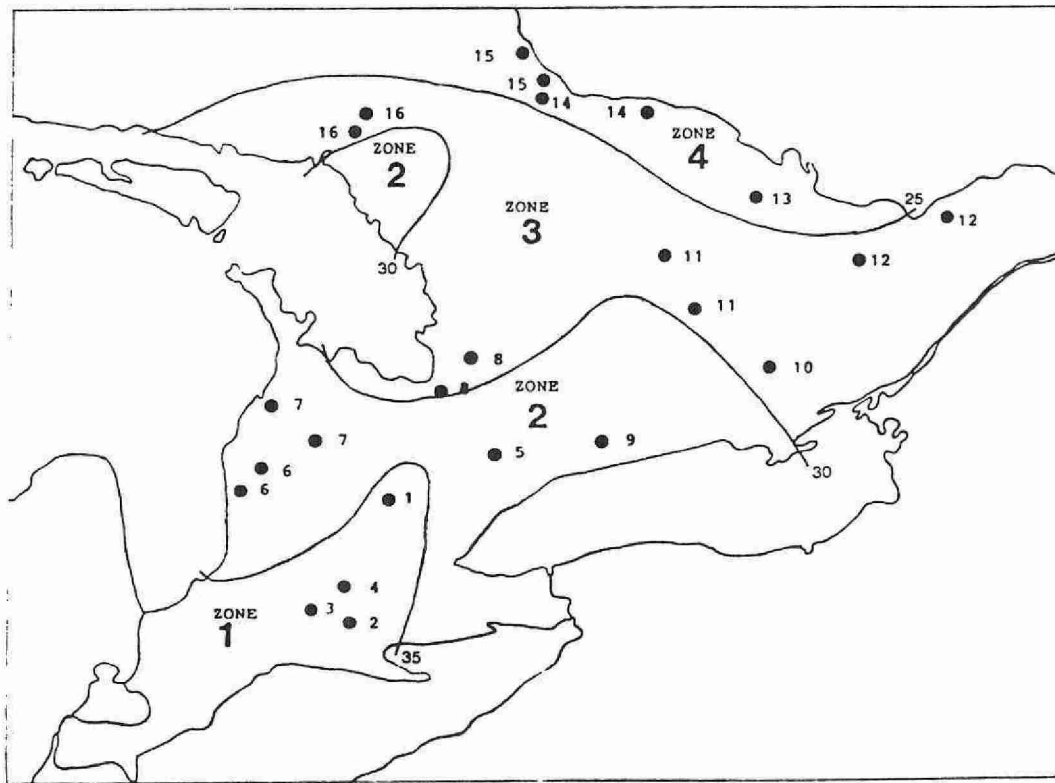


Figure 9: Distribution of foliage sampling sites within four sulphate deposition zones.

	(1 kg wet SO ₄ /ha/yr)
Zone 1	> 35
Zone 2	30 - 35
Zone 3	25 - 30
Zone 4	< 25

D. MNR WILDLIFE STUDIES

Cadmium Levels in Ontario Moose and Deer

A 1985-1986 study measured the concentration of cadmium in the kidney, liver, muscle and hair in Ontario moose and deer. This study was in response to a 1984 preliminary study by the Ontario Ministry of Natural Resources where researchers found that cadmium concentrations in moose tissue from a Huntsville, Ontario site were two to three times higher than those found in Sweden.

The objectives of the 1985/86 study were to:

1. examine the concentration of cadmium in kidney, liver, muscle and hair of moose and white-tailed deer;
2. investigate regional and age class differences in cadmium content of moose and deer;
3. provide data for decision-makers on implications for human health.

A total of 1,133 moose tissue samples and 1,787 deer samples were analysed in 1985-1986. Sampling sites were selected based on their buffering capacity (Fig. 10), since there has been concern that areas characterized by poorly buffered soil may have higher levels of cadmium because of accelerated leaching due to increased acid precipitation. Samples were also collected from outside these target areas (not included in Fig. 10) and the analysis of these data is underway. For moose, the highest mean levels of kidney cadmium were found in Algonquin, Cornwall, and St. Joseph Island (Fig. 11), and for deer, at the Loring and Peterborough sites. This suggests that buffering capacity may not be a major influence on cadmium levels as expected since St. Joseph Island, Cornwall and Peterborough are

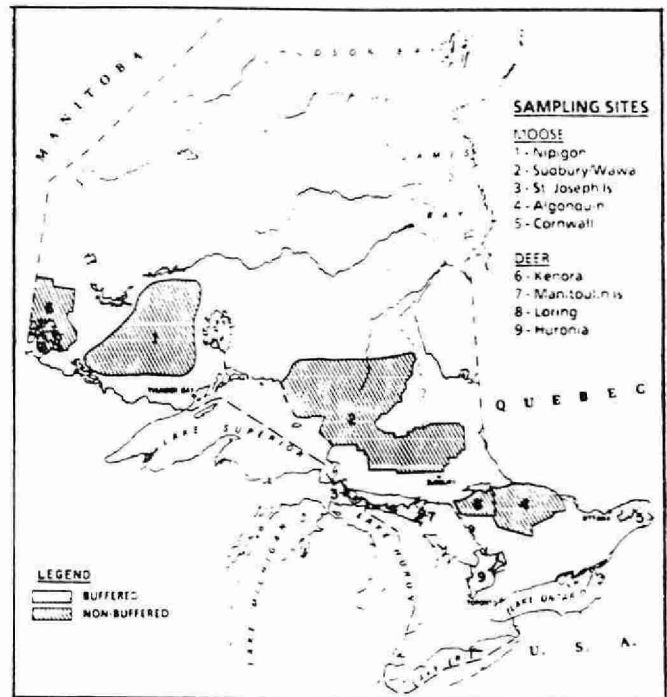


Figure 10: Sampling sites for moose and deer tissue.

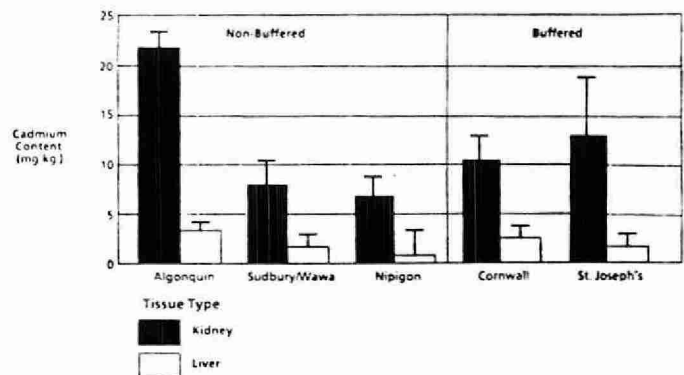


Figure 11: Mean cadmium content in the kidney and liver of moose in buffered and non-buffered sites. Levels of cadmium in muscle tissue were extremely low and are not shown on this figure. Error bars represent standard error of the mean.

chemically buffered sites. In all regions the level of cadmium was highest in kidney, lower in liver and hair and often undetectable in muscle. Cadmium concentration increased with age.

Consumption limits for moose and deer tissues were established according to the World Health Organization limit of 0.5 mg cadmium per week. A fact sheet was issued which recommended that liver and kidney were not suitable for human consumption. The muscle cadmium levels were low enough for the safe consumption of moose or deer meat.

Levels of cadmium in Ontario moose are comparable to or higher than those found in Quebec and are considerably higher than those found in Manitoba, Maine and Scandinavia. The cadmium levels in the kidney and liver of white-tailed deer in Ontario were considerably higher than levels found in Quebec but lower than those in Pennsylvania.

The study was expanded in 1987 to include mercury, manganese, nickel, lead and zinc and data analysis is presently in progress.

Ongoing work will investigate the pathway of cadmium uptake in deer forage and cadmium build-up in selected moose tissues.

Natural Cadmium Pathways in the Foodchain of Northwestern Ontario Moose

A 1987 study investigated cadmium accumulation in aquatic and terrestrial moose-preferred plants. Samples were taken from the vicinity of the GECO copper-zinc-silver mine at Manitouwadge, northwestern Ontario, (a site known to be naturally enriched with cadmium) and from a background site.

Results showed that the incidence of soil and sediments with enhanced cadmium levels is strongly correlated with their proximity to, and probable derivation from, cadmium-bearing rocks. Cadmium-bearing terrestrial plants (Abies balsamea, Betula papyrifera, Populus tremuloides) are more consistent indicators of cadmium bearing soils and sediments than the aquatic plants in this study. The aquatic

plants Myriophyllum exalbescentis and Utricularia vulgaris have the highest cadmium concentrations of all plants tested and these reflected the range of cadmium contents in their associated sediments.

Relationship of Soil Acidification to Cadmium Levels in White-tailed Deer Forage and Pellets

This program has been set up to determine cadmium levels and pH of surficial soils in deer yards designated as either geophysically sensitive (non-buffered) or tolerant (buffered) to acid precipitation. It is also designed to relate cadmium burdens in surficial soils to levels present in major forage species of deer, and to assess the use of deer faecal pellets as bioindicators of the availability, exposure level and/or body burden of cadmium.

In contrast to the suggested conclusions from the study on cadmium levels in moose and deer results to date have shown increased cadmium levels in the acidified soils of non-buffered sites and higher pellet cadmium levels in the non-buffered deer yards than in the buffered yards. Work in 1988 will attempt to correlate cadmium burdens of forage, pellets and soil with cadmium body burdens accumulated by resident deer.

Cadmium Levels in Black Bears

Black bears may be vulnerable to cadmium contamination because a large portion of their diet consists of vegetation which may have high concentrations of cadmium. The cadmium biomonitoring program was expanded in 1987 to include a limited sampling of bear tissue in order to establish cadmium levels in bears and appropriate guidelines for human consumption.

Bears were taken from three regions: Algonquin (south-central Ontario), and northern and northeastern

Ontario. In general, cadmium levels were highest in kidneys, lower in liver and hair and lowest in muscle (Fig. 12). A similar pattern was found in moose and deer. Cadmium levels increased with age, however, there were no significant differences among regions. The cadmium concentrations were in a similar range to those found in moose and deer.

Based on the high cadmium concentrations bear kidney and liver are considered unsuitable for human consumption while bear muscle is acceptable.

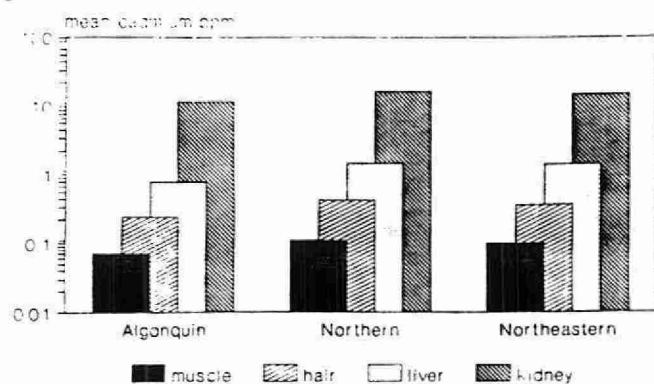


Figure 12: Mean cadmium content in muscle, hair, liver and kidney of bear sampled from three regions.

BIOGEOCHEMISTRY STUDIES

A. BIOGEOCHEMICAL STUDY SITES - MONITORING PROGRAMMES

The biogeochemistry studies provide baseline data about the physical, chemical and biological state of the watersheds. The results help to determine the changes that occur with continuing acid rain.

The APIOS program has established watershed study sites near Dorset (south-central Ontario) and near Thunder Bay (northwestern Ontario). The study catchments located at Plastic and Harp Lakes in south-central Ontario are in a high sulphur deposition area while the Hawkeye Lake site in northwestern Ontario is in a low loading area.

All three sites lie on the Precambrian Shield, the location of most of Ontario's productive forest land. The Shield represents the area most sensitive to acidification and includes prime wilderness and recreational resources.

The Plastic Lake site has shallow soils with mainly coniferous trees while the Harp Lake site has deeper soils with mainly deciduous trees. Soils in the Hawkeye Lake site range in depth from very shallow to over 65 feet, with a mixed forest stand.

These intensive 'biogeochemical' studies focus on the chemistry of an entire catchment and emphasize the links between land and water systems. Inputs of rain and snow undergo changes as they pass through the forest canopy, through the forest floor and underlying soil, and finally as they emerge as streamflow discharged from the watershed.

Routine sampling occurs at all three sites. Bulk samplers monitor precipitation quantity and quality. Lysimeters collect the water percolating through the soil and weirs (Fig. 13) monitor water quantity in the streams draining the study areas.

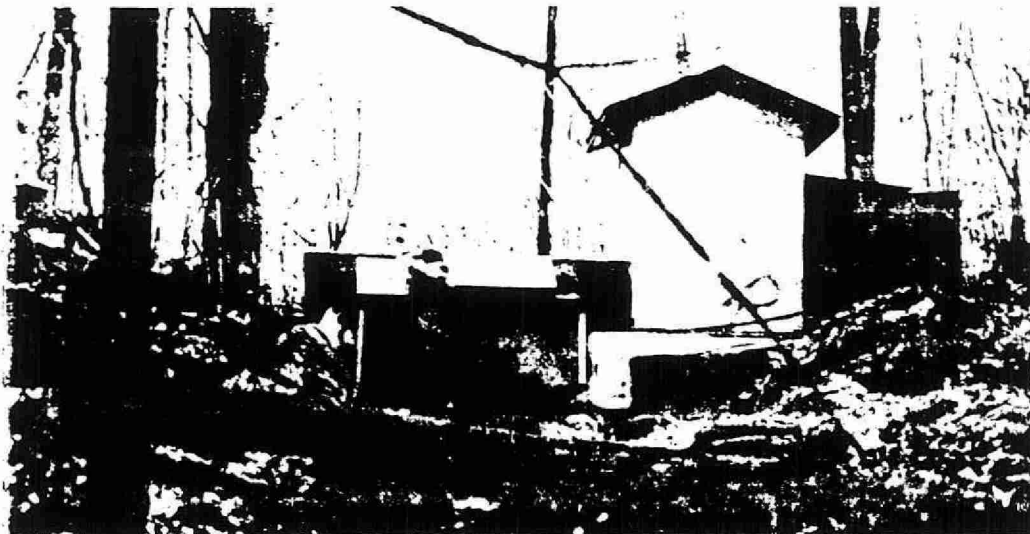


Figure 13: Inflow weir at Harp Lake.

B. PROCESS STUDIES

Bioaccumulation of Nutrients

Estimates of the standing crop and annual increment of basic cations, (nitrogen, sulphur and phosphorus) will be made in the upland forest ecosystem of the Harp and Plastic sites. These estimates will include major tree species, litter and organic soil components.

Researchers will use these data to calculate the rate of proton production as a consequence of forest growth as well as the rate of base cation loss from soils.

Comparisons of standing crop measurements will be made between stands, and with other forest stands in different deposition zones. These estimates will be integrated with known nutrient requirements of major tree species and with soil content and availability of these nutrients. The study results will ascertain the adequacy of current rates of nutrient uptake to maintain normal forest productivity and possible effects of acid deposition on these rates.

The stand table reports for two subwatersheds (one at Harp Lake and one at Plastic Lake) will be completed by the end of the 1988/89 fiscal year with an assessment of biomass accumulation in the two subcatchments.

Mineral Weathering Rates

The purpose of this study is to identify the important weathering reactions that occur within a catchment and estimate the whole catchment rate of these reactions.

Experimental projects will evaluate the effects of strong, weak, and complex organic acids on the nature and rate of weathering. The reactions will then be related to runoff water composition of local and regional catchments.

Several soil profiles from Plastic Lake were examined to determine the mineral removal rates from soils, and to determine the relative importance of different minerals.

Preliminary results indicate that most cations have experienced a 25% loss on average and that plagioclase feldspars are the most important minerals for neutralizing acidity. A report on "Weathering rates from soil profiles" will be completed by the end of fiscal year 1988/89.

In another project, the Secondary Ion Mass Spectrometer (SIMS) was used to investigate the near-surface composition of naturally weathered plagioclase. These analyses indicated that the surfaces are depleted in silica by as much as 70%, relative to unreacted feldspar. It is proposed that the destruction of the silica depleted feldspar surface is controlled by surface reactions. Also, aluminum concentration in solution may be controlled by the silica depleted surfaces.

The mineral weathering information will ultimately be incorporated in the models of long-term changes in stream chemistry to determine the rate of acidification in the aquatic systems in the Muskoka-Haliburton area.

Aluminum Geochemistry in Catchments Stressed by Acid Deposition

Acidification increases aluminum levels in aquatic systems. The purpose of this study is to determine the sources and mechanisms of these increased levels.

The theory that differences in bulk soil extractable aluminum are translated into differences in soil solution chemistry is being tested by a comparison of the soil solution chemistry of Harp and Plastic catchments. These catchments have significantly different bulk soil aluminum chemistry. The results

show that the B soil horizon is the major inorganic aluminum source.

Leaching experiments are investigating the mineralogical differences between Plastic and Harp Lake soils. These experiments will identify which compounds dissolve into solution and cause the high aluminum levels. Preliminary results indicate that gibbsite solubility is controlling aluminum levels.

AQUATIC EFFECTS STUDIES

A. CHEMICAL STUDIES

Calibrated Watersheds

a. Chemical Limnology

The Limnology Section of the Water Resources Branch has been monitoring a set of 20 streams and 8 lakes in the Muskoka-Haliburton area for 5 to 12 years (Fig. 14). These data are used to measure the long-term effects of acid deposition and trace metal inputs on the chemistry and biology of the study lakes and streams.

A summary paper of the most recent results described the changes in Plastic Lake. Direct observations of Plastic Lake between 1979 and

1985 showed a threefold decrease in alkalinity, and a decrease in pH of 0.2 units (Fig. 15).

The lake's acidification has resulted in extensive damage to biota including the extinction or near-extinction of certain mollusc and crustacean species, increased growth of undesirable filamentous algae species, and some mortality of fish.

Plastic Lake has continued to acidify because of the continuing release of sulphate from the catchment. The recent decreases in sulphur dioxide emissions may decrease the rate of acidification of Plastic and other lakes, but further decreases in deposition are necessary to actually reverse the damage.



Figure 14: Location of the study area (Muskoka-Haliburton) showing approximate areas (shaded) of high sulphur dioxide and nitrogen oxide emissions.

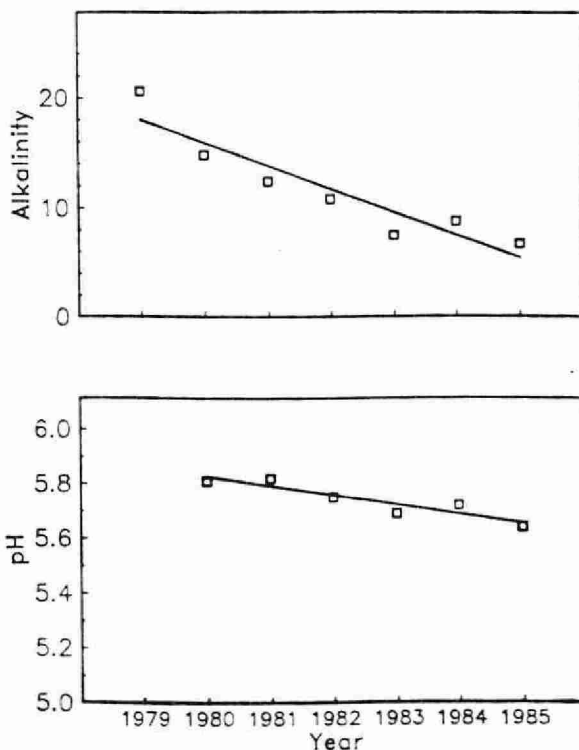


Figure 15: Alkalinity (ueq/L) and pH in Plastic Lake between 1979 and 1985.

b. Lake and Stream Models

Data collected as part of the lake monitoring study are used to develop and calibrate several models.

These models can be used as both investigative and predictive tools.

As investigative tools, they examine the efficacy of the scientific concepts being modelled. As predictive tools, they predict changes in pH or alkalinity as well as other parameters under different loading scenarios.

The modellers use the data from the ongoing monitoring programmes to refine the models and to improve their accuracy of prediction.

Policy analysts will ultimately apply the models to compare the benefits of various control strategies.

c. Metal Contaminants

Mercury levels in fish from acidified lakes tend to exceed those from non-acidified lakes. The sources of mercury in sensitive areas must be identified and the relationships between mercury concentrations in water and levels in biota need to be determined.

Ministry scientists have developed a new solvent extraction technique capable of analyzing for ultra trace concentrations of mercury in water. The procedure is used to analyze stream, lake, and precipitation samples in the Muskoka-Haliburton area.

By combining these data with hydrologic data, researchers will be able to quantify the relative importance of the loadings of mercury to the lakes from the air and from the watershed. They will also examine the influence of watershed characteristics on the retention or release of mercury.

Present data indicate that brown-water streams contain two to five times more mercury than clear streams and that the mercury concentration in precipitation usually exceeds that of surface waters.

Crude budget calculations suggest that precipitation is a major route of mercury input to streams.

d. Extensive Lake Sampling

A number of new lakes surveyed during 1987-88 will be included in the Acid Sensitivity of Lakes in Ontario guide. These surveys were designed to fill in geographical and chemical gaps in the extensive lake data base which now contains over 6,000 lakes. In order to fill these gaps, a number of smaller lakes (less than 10 hectares) were included in each survey.

The Northwestern Region surveyed 98 remote lakes in northwestern Ontario, north of Red Lake, during the spring. The results of this survey added valuable data to our data base, since the lakes were in an area where atmospheric deposition is as close to 'background' as can be found in Ontario on the Precambrian Shield.

The sulphate levels in these lakes were extremely low. This observation is consistent with our thesis that atmospheric deposition is the major source of sulphate in Ontario's lakes.

Despite the occurrence of lakes with extremely high colour, no acidic lakes were discovered. The pH of these high coloured lakes averaged 7.0 with only one lake at pH less than 6.0. These results support our contention that natural organic acids alone are not sufficient to produce acidic (negative alkalinity) conditions in lakes, and that the presence of a strong mineral acid (sulphuric acid) is also required.

The second project was a survey of lakes in the southeastern portion of the province. Staff with the Southeastern Region surveyed lakes which would fill a gap in the water chemistry data base for this area. Previous surveys had been limited to pH, alkalinity, and conductivity. This survey included major anions and cations, and metals associated with acid deposition. Many of these lakes lie on limestone bedrock and are well buffered, however, the sulphate levels were consistent with geographic trends in other less buffered lakes.

The Northeastern Region continued its lake survey programme with a bias to lakes smaller than ten hectares. Previous surveys provided reasonably good geographic coverage of the area, but most of the data pertained to larger lakes. Annual monitoring has continued on a subset of 43 Sudbury area lakes, and

indicates that chemical recovery related to SO₂ emission reductions appears to be continuing (Fig. 16).

The effects of sulphur deposition on lake chemistry on a regional scale were assessed using a subset of the extensive lakes data base. Ontario was divided into zones based on total sulphur deposition which decreased from south to north.

An analysis of the chemical data collected for a total of 1,180 soft-water lakes surveyed between 1981 and 1987 showed a strong relationship between both the mean lake pH and mean lake alkalinity and the sulphur deposition of the zones (Fig. 17, Fig. 18 and Fig. 19). Assuming that the chemical characteristics in the lowest deposition zone indicate 'background conditions', substantial alkalinity has been lost in all of the other regions.

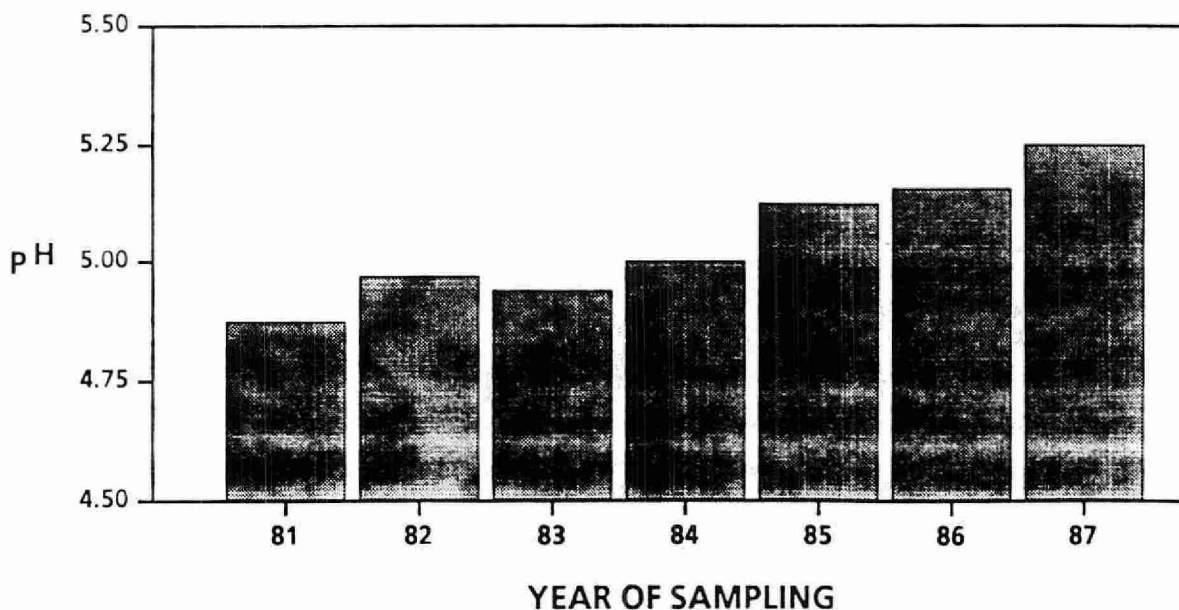


Figure 16: Annual average pH for 43 Sudbury area lakes, 1981-1987.

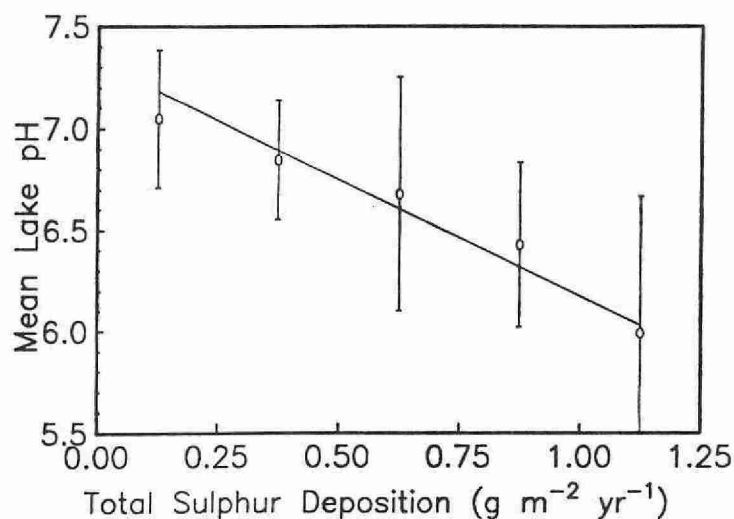


Figure 17: Relationship between total sulphur deposition (grams/meter²/year) and average lake pH.

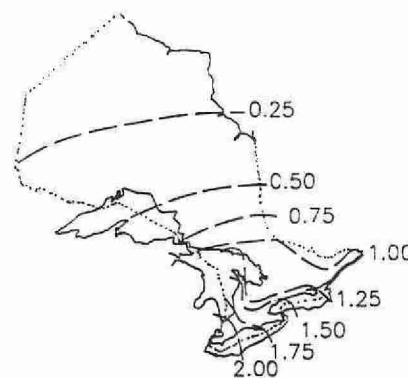


Figure 18: Division of Ontario into sulphur deposition zones (total sulphur deposition (grams/meter²/year))

B. BIOLOGICAL STUDIES

Algae

a. Chrysochromulina breviturrita - odour

Lakewide odour problems developed on Dickie Lake (McLean Twp.) in June of 1987 and persisted through much of the summer. The total number of known odour episodes attributed to C. breviturrita from Ontario and the New England States is now 13 (1978-1987). In 1987 a data base containing abundance of C. breviturrita and physical/chemical data for 267 Ontario lakes was analyzed to determine possible relationships between C. breviturrita and environmental variables. Canonical correlation analysis showed a significant negative relationship between C. breviturrita and pH and a positive relationship between the algae and DOC. There were significant but weaker correlations with iron, manganese, aluminum, nitrogen and phosphorus.

The laboratory work with cultures of C. breviturrita has been completed. The objectives of the research were

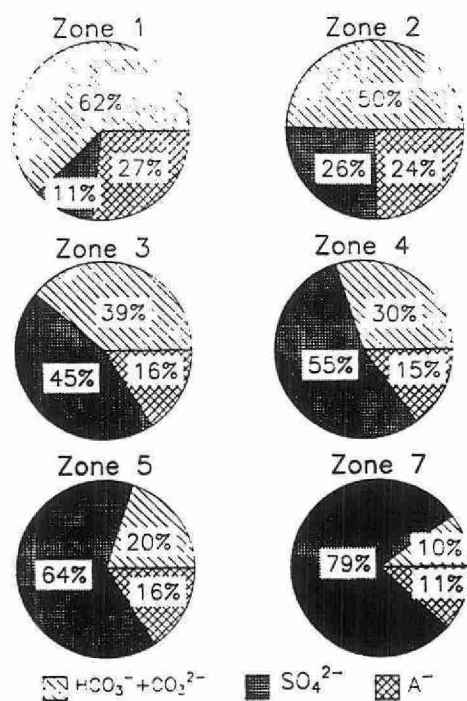


Figure 19: Percent anion composition of lakes in the different deposition zones. Zone 6 is not shown since it is an insensitive area due to limestone buffering.

to define the general chemical conditions necessary for algal growth. Results show that C. breviturrita will only grow in water with low pH and alkalinity. Selenium is an essential nutrient for growth, and the algae will not utilize nitrate as a source of nitrogen.

b. Lake pH - Algal Sediment
"Fossils"

The down-core sections from Plastic and Clear lakes (Sherborne Twp.) were analyzed for both diatom frustules and chrysophyte scales. Statistical analyses of the diatom and water chemistry data from the 50 lake calibration set were completed and a draft report was prepared entitled "Parameterization of calibration equations relating diatom "microfossils" to surface-water pH and alkalinity in central Ontario Lakes". The diatom taxonomy included in this report is currently being updated.

A draft report entitled "Sedimentary chrysophycean cyst assemblages as paleoindicators in acid sensitive lakes" is currently undergoing internal review. Taxonomic work on the identification of Mallomonas spp. continued and several journal papers were published in 1987-88.

c. Filamentous Algae

Algal mapping of Swan Lake was used to determine changes in algal growth due to pH increases since 1981-82. Results show that there has been a decrease in algal abundance as pH increased. An additional survey is planned for 1988 to substantiate these changes. The sixth consecutive year of algal mapping was completed in Bowland Lake (whole-lake neutralization study), and Lake 302S (whole-lake acidification study). Increased growth of algae in Bowland Lake (which is now reacidifying), and Lake 302S, is consistent with acidifying systems.

Annual mapping of Plastic Lake (seventh consecutive year) was continued. These data are used to evaluate seasonal and year to year changes in algal growth. Plastic Lake also serves as a valuable reference to assist in the interpretation of algal growth on less intensively studied lakes. Aerial mapping of Lake of Bays (second consecutive year), was also continued. Results showed that about 5% of the shoreline (mostly in the smaller bays) was covered with filamentous algal clouds. This may be an indication of early acidification.

A follow-up Statistical Report (to the Cottager Questionnaire Survey) was received and it related lake physical/chemical characteristics to predicted algal status. Lake pH was one of several statistically significant variables that explained algal presence. A second contract was awarded to further this evaluation.

A report was received on the taxonomy of Zygnemataceae in Ontario lakes. Results show an apparent pH preference associated with various species of filamentous algae.

Zooplankton

Various studies are underway to determine the effects of acidification on zooplankton in Precambrian Shield lakes.

A comparison of data from a number of surveys confirmed that relatively modest pH depressions can reduce the biomass of the dominant Daphnia species.

Chaoborus abundance does not necessarily increase after acidification as previously suspected. Replacement of acid-sensitive by acid-tolerant zooplankton species (e.g. Holopedium) and an increase in rotifer biomass may accompany lake acidification.

Rates of zooplankton recovery after neutralization of acid, metal-contaminated lakes are slower than anticipated. Even though communities may change after pH increases, they do not necessarily recover attributes of non-acidic lakes.

Preliminary calculations for lakes in the Dorset area suggest that after correction for differences attributable to nutrients, zooplankton biomass increases with increases in pH.

Invertebrates

The effects of short-term increases in aluminum and hydrogen ion concentrations on stream insects were studied at two locations: Dorset (high acid loading area) and ELA (low acid loading area).

Field experiments in streams showed that some species of mayflies, midges, and blackflies avoided high acid and aluminum concentrations at the ELA sites but not at Dorset. The macroinvertebrate consumers showed a greater sensitivity to decreases in pH at ELA than at Dorset. This suggests that some of the organisms at Dorset have at least partially adapted to the high acid stream conditions.

Scientists are comparing the Algonquin Park stream insect data collected 50 years ago with data collected recently (1984-1986). They observed the same species in 1984-86 as were observed 50 years ago where pH shifts were small (6.4 - 5.7), but, at sites where large pH decreases occur (6.4 - 4.9), most mayfly and stonefly species present 50 years ago had disappeared by 1984-86. Some of these species are known to be sensitive to low pH. The findings are consistent with the hypothesis that poorly buffered surface waters have acidified somewhat over the past 50 years.

Preliminary data analysis indicates that the biomass for some insects (mayflies) has declined in the last 50 years, and that the biomass for other species (blackflies) has increased at sites subject to spring pH depressions.

Toxicity Studies

The MOE toxicity research on sport fish has been completed. MOE scientists are finalizing reports on the following studies:

- Effects of snowmelt-induced changes in water chemistry on the survival of caged lake trout and brook trout;
- Lethality of hydrogen ion and aluminum to early life stages of six softwater fish species (Fig. 20);
- Sensitivity of seven fish species to short-term elevated hydrogen ion levels during an artificial stream acidification;
- Early life stage survival of lake trout and brook trout during chronic exposures to waters of various pH and aluminum concentrations;
- The sensitivity of various fish species, stocks, and age classes during 7-day in situ exposures to acidified waters.

The MOE research on eggs and fry of native Ontario sport fish has shown that the hydrogen ion is more important than aluminum as a toxicant.

Recently, acute lethality studies of metal mixtures (aluminum, copper, zinc, iron, manganese, nickel, and lead) at ratios typical of acidified waters were conducted with rainbow trout and fathead minnow larvae in soft, acid water. For trout, a low pH tolerant species (median lethal pH = 4.4), aluminum alone accounted for the mixture toxicity at pH 4.9,

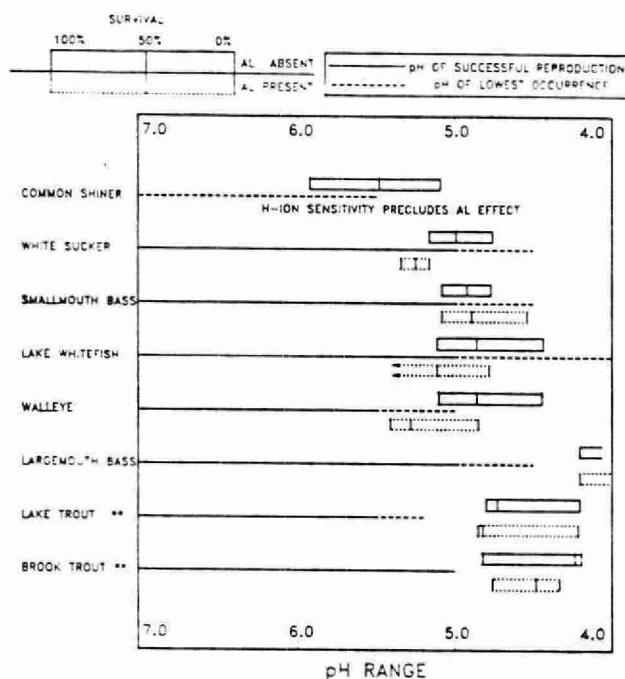


Figure 20: Utility of laboratory toxicity testing in predicting responses of eight fish species to acidification. Box plots summarize response of most sensitive life stage of each species to hydrogen ions to hydrogen ions plus aluminum, as determined in laboratory studies done at Dorset. Horizontal lines summarize pH of successful reproduction and lowest occurrence established from field surveys in eastern North America from published literature by other researchers.

while copper alone accounted for the mixture toxicity at pH 5.8.

For acid-sensitive fathead minnows (median lethal pH = 5.3 - 5.5), copper appeared as the main toxic metal at pH 5.8.

Current toxicity studies are concentrating on the toxicity of acidity alone or in combination with other factors to commonly abundant species of cyprinids or forage fish and invertebrates (snails, amphipods, *Mysis relicta*, and some insects).

Field data suggest that these species are very sensitive to hydrogen ions, but, none of these species have been tested in controlled laboratory experiments. Laboratory toxicity tests will provide the cause-effect relationships and determine species sensitivity.

Chronic and acute toxicity tests on fathead minnows are scheduled for the current year.

Biological Survey

Previous research has concentrated on the adverse effects of acidification on sport fish. Recently, the emphasis has shifted to the most sensitive organisms, the benthic invertebrates that form the main part of the diet for some sport fish.

Biological surveys of softwater Shield lakes will quantify the extent of these damages. They will identify aquatic invertebrates that may be sensitive to low pH and will quantify their response to low pH as a function of lake chemistry.

Sampling of the littoral zone (shallow water) invertebrate community was completed on approximately 60 lakes during the fall of 1987. The biological samples are being processed to identify species to the lowest taxon. Statistical analyses of the chemical and biological data will determine any significant relationships between the chemical parameters and the occurrence of particular biota.

Biological Monitoring

Researchers have documented several cases of local, abrupt species extinctions (e.g. snails (*Amnicola*) in Heney Lake, amphipods (*Hyallela*) in Plastic Lake). The data suggest that besides hydrogen ion sensitivity, certain life history characteristics lead to a high

probability of extinction over a short period of time. These extinctions occur when degradation in lake water chemistry is relatively slight.

Depending on the species selected, a lake monitoring program could detect population losses over a short period of time. As such, a program is being developed where lakes within a range of sensitivity will be routinely sampled. This sampling will concentrate on species that are normally abundant, have short life spans, and are believed to be sensitive to hydrogen ions (gastropods, amphipods, crayfish, leeches, insects and possibly cyprinids).

Currently, researchers are testing and comparing a variety of sampling techniques and schedules. Finally, an optimum method will be devised and used in succeeding years.

The monitoring data will be integrated with data collected by the Department of Fisheries and Oceans. Investigators will then use the combined data set to examine regional and temporal trends of community composition.

Metal and Organic Residue Monitoring

a. Monitoring Mercury Levels in Yearling Yellow Perch

This program is in its tenth year for lakes in Muskoka-Haliburton with fewer years of data in the Sudbury, Chapleau and Thunder Bay areas. Using data collected over the period 1978-87, pH explained 64% of the variability in mercury in yearling yellow perch in 15 lakes in Muskoka-Haliburton (Fig. 21). There were no trends in mercury levels in the perch over the ten year period (1978-1987) in any of the lakes.

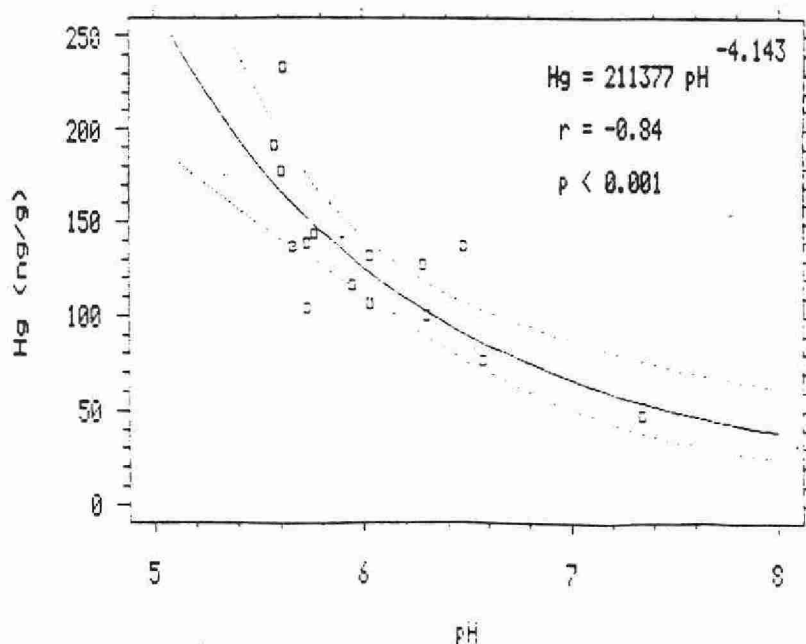


Figure 21: Relationship between lake pH and mercury residues in yearling yellow perch in the Muskoka-Haliburton study lakes.

b. Investigating Relationships
Between Mercury in Sport Fish
and Lakewater Quality

Data collected under the Contaminants in Sport Fish Program and the Acid Sensitivity Program were used to assess the relationship between lake water quality and mercury in sport fish. The focus to date has been on lake trout and smallmouth bass. Dissolved organic carbon was the only variable that explained a significant amount of variation (37%) in mercury in standard length lake trout. Higher mercury levels were found in trout from lakes of higher dissolved organic carbon concentration in 61 lake trout lakes.

Using a similar stepwise linear regression approach, calcium, dissolved organic carbon and latitude were the variables which explained a significant amount (47%) of the variation of mercury in standard length smallmouth bass. Higher mercury levels were found in lower latitude lakes with lower calcium and higher dissolved organic carbon concentrations in 56 bass lakes.

Water quality information on more than 200 walleye and pike lakes was collected in the winter of 1987/88 to provide a data base suitable for further investigations on links between mercury in these species and lakewater quality.

c. Investigating Relationships
Between Mercury in Sport Fish
and Lake Sediments

By integrating sediment data from the Geological Survey of Canada Uranium Reconnaissance Program with the aforementioned mercury in fish and water quality data bases, mercury in lake sediments did not account for a significant amount of the variability of mercury in either lake trout or smallmouth bass. Since sediments were from a depth which represent "background" levels (indicative of watershed inputs to

the lake), these results indicate that differences in geological mercury between watersheds do not account for differences in the mercury content of fish.

MNR Fish Studies

a. Current Impact of Acidic
Deposition on Sport Fish Species
in Ontario

Field and laboratory toxicity data, and field population data were used to determine the pH levels corresponding to population losses among Ontario's major sport fish species (lake trout, brook trout, smallmouth bass and walleye).

Chemical survey data collected from 1978-1985, from 743 to 863 lakes per species were then used to estimate the extent of damage to sport fish resources in Ontario. An estimated 4.6% (n=106) of lake trout, 0.8% (n=18) of brook trout, 1.6% (n=38) of smallmouth bass and 0.1% (n=6) of walleye lakes have lake pH below their respective lethal thresholds. Most of these lakes are located in the Sudbury area which historically received high loading of acidic deposition from local smelting operations. Of the four species, lake trout appears to be at greatest risk because of its intolerance to low pH (pH threshold of 5.5), the high proportion (62%) of the species' lakes located in the high deposition zone (area receiving greater than 15 kg/ha/year wet SO₄ deposition) and the high proportion (20%) of the lakes with little or no buffering capacity (alkalinities less than 40 ueq/L). Although brook trout lakes generally have very low alkalinities, brook trout usually spawn over groundwater upwellings which provide a chemical refuge for the sensitive early life stages.

b. Factors Controlling Fish Species
Richness

Survey data from 2,931 Ontario lakes were analyzed to determine how fish species richness was empirically

related to a set of 19 physical and chemical limnological variables. Lake area was the dominant factor, explaining 18% of the variation in species number (as lake area decreases so does species number). Total aluminum, latitude, dissolved organic carbon, and elevation together explained an additional 16%. The strong relationship between species number and lake area was quantified using lakes with pH values greater than or equal to 6.4 and then applied to all the surveyed lakes to estimate species number. Deviations from the expected value indicated that species number decreased with decreasing pH below pH 6.0, resulting in significantly fewer species in lakes with pH less than 6.0. In the subset of lakes with pH less than 6.0, pH alone explained 21% of the variation in species number: elevation, lake area, and dissolved organic carbon together explained an additional 20%. Interactions between pH and lake area were identified: lake size decreased significantly both at low pH (less than 6.8) and at high pH (greater than or equal to 7.7).

A set of 574 Ontario lakes, which were sampled intensively for both small and large fish species, was analyzed to determine the relationships between the number of

cyprinid (minnow) species and the variables lake area and pH. A re-examination of the relationships between total number of species and lake area and pH produced more accurate results than those obtained earlier using a less intensively sampled lake set (Fig. 22). Total number of cyprinid species was largely independent of lake area, and declined with pH below 6.0. The ratio of cyprinid species number to total species number increased with decreasing lake area. When lake area effects were accounted for, the ratio decreased with pH below 6.0. The magnitude of the change was small initially, and increased with smaller values of pH. Accordingly the decline in total species richness with pH is initially due to both large and small species, with cyprinids contributing proportionately more to the reduction as pH decreases.

Future work will focus on the individual species of small fish, mostly cyprinids, that are most common in acid sensitive lakes in Ontario. We will examine the variables which determine the presence or absence of a particular species in a lake and assess the utility of each species as an early indicator of fish community changes due to acidification.

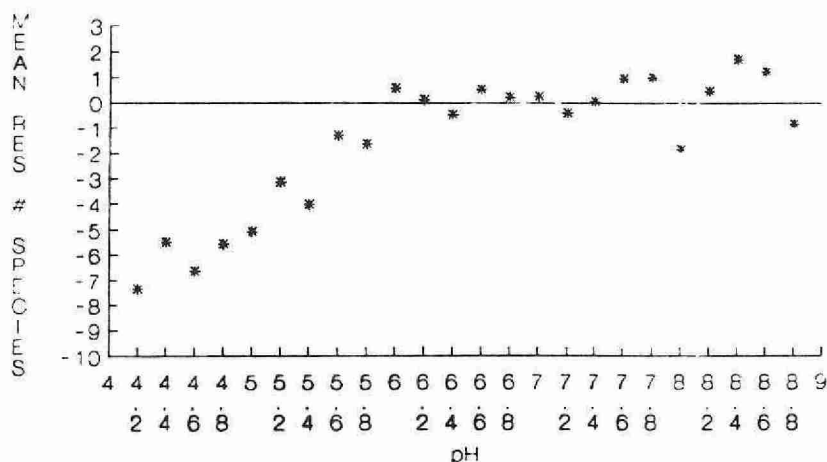


Figure 22: Mean residual number of species by pH interval. The residual number of species for a lake is the deviation of the observed number from the number predicted by lake area.

c. Trend-Through-Time Monitoring of Fish Communities in Acid Sensitive Lakes in Ontario

A trend-through-time monitoring program began in 1982 to establish baseline data from which to assess long term effects of acid deposition on fish communities in 20 low alkalinity ($0 - 2.6 \text{ mg}\cdot\text{L}^{-1}$ as calcium carbonate) lakes in south-central Ontario. The study lakes were all clear (dissolved organic carbon less than $4 \text{ mg}\cdot\text{L}^{-1}$) and dilute (conductivity less than $35 \text{ }\mu\text{S cm}^{-1}$), but differed in size ($11 - 607 \text{ ha}$) and fish community composition ($2 - 18$ species).

Monitoring included assessment of: fish species presence, abundance, age composition, growth, recruitment, and angler harvest. Field toxicity tests were used to test the direct toxicity of lake or runoff water to sensitive life stages of various indigenous fish species.

Many of the lakes contain fish species known to be highly sensitive to low pH, therefore, these lakes represent good candidates for the assessment of long-term changes (Fig. 23). To date, no anomalous population characteristics such as loss of species, or occurrence of persistent recruitment failures, have been identified that can be related to acidification of the study lakes.

With additional years of data, this long-term monitoring program should prove to be extremely valuable for assessing the effects of acidic deposition and perhaps other atmospheric pollutants on fish communities in low alkalinity lakes.

d. Resurvey of Sudbury Lakes: Recovery

Lake trout ($n=36$) and brook trout lakes ($n=20$) around Sudbury are being resurveyed (initial survey: 1982-1984) to assess fish community changes due to reduced emissions.

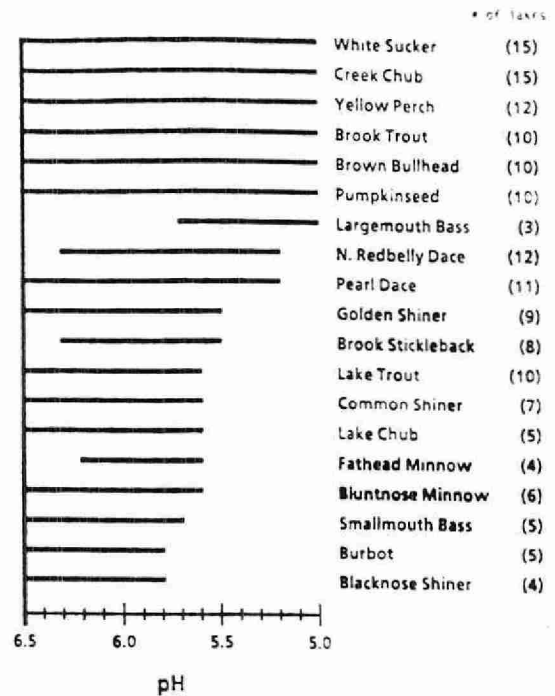


Figure 23: Occurrence of fish species in the trend through time study lakes across a pH gradient.

e. Chronic Effects of pH, Calcium, Sodium, and Aluminum on the Survival of Five Stocks of Lake Whitefish (*Coregonus clupeaformis*) Embryos and Larvae

Lake whitefish eggs were collected from five stocks (Bay of Quinte, Lake Ontario (1985, 1986); Lake Simcoe (1985, 1986); Lake Opeongo (1985, 1986); Smoke Lake (1986); Carson Lake (1985)) and artificially fertilized. Embryos were incubated over a range of pH (3.5 to 7.0) and calcium ($1.0 \text{ mg}\cdot\text{L}^{-1}$ to $64 \text{ mg}\cdot\text{L}^{-1}$) levels. A subset of treatments were also exposed to two levels of aluminum (0.2 , $0.4 \text{ mg}\cdot\text{L}^{-1}$) and sodium (1.0 , $4.0 \text{ mg}\cdot\text{L}^{-1}$). Eggs were incubated in static tanks with regular water exchanges. Temperature was controlled to simulate the natural cycle for a typical southern Ontario whitefish spawning shoal. Mortality at three life stages (non-eyed eggs, eyed eggs, and larvae) was recorded bi-weekly.

Calcium was found to have an ameliorating influence on acid tolerance. For example, increasing calcium from $1.0 \text{ mg}\cdot\text{L}^{-1}$ to $4.0 \text{ mg}\cdot\text{L}^{-1}$ lowered the pH that produced 50% egg mortality from 5.32 to 4.96. At low calcium levels (e.g. $1.0, 2.0 \text{ mg}\cdot\text{L}^{-1}$), even moderately reduced pH levels (5.81, 5.63, respectively) caused significant overwinter egg mortalities (10% above controls). Increasing sodium from $1.0 \text{ mg}\cdot\text{L}^{-1}$ to $4.0 \text{ mg}\cdot\text{L}^{-1}$ increased non-eyed egg mortality and decreased eyed egg mortality by about an equivalent amount so that total mortality of eggs was unaffected. No effects of increased sodium on larval survival were observed. At both aluminum concentrations, non-eyed egg mortality was decreased and eyed egg and larval mortality was increased. The five stocks were significantly different in pH tolerance at all three life stages examined. Data collected over the two years showed that for all three life stages, and at all pH, calcium and sodium levels, the Lake Opeongo whitefish are consistently the most tolerant and the Lake Ontario whitefish the least. There was no difference in aluminum tolerance among the stocks.

f. The Effects of Temperature, pH and Water Hardness on Winter Starvation of Young-of-the-Year Smallmouth Bass

Starvation over the first winter of life is a critical process for determining year-class strength in northern populations of smallmouth bass (*Micropterus dolomieu*). We examined starvation among young-of-year bass under both summer and winter conditions. During starvation, body condition declines to a specific level and then the fish dies. Body condition at death is a well defined function of body size and remains relatively constant over a wide range of environmental conditions. Starvation rates vary systematically with body size,

temperature, pH and water hardness. Available stored energy increases more rapidly with body size than starvation rate, therefore, lifetime under starvation conditions tend to increase with increasing body size. Starvation rate increases linearly as pH declines from 7.0 through to 4.9. Starvation rate increases as calcium concentration declines from $80 \text{ mg}\cdot\text{L}^{-1}$ to $1 \text{ mg}\cdot\text{L}^{-1}$.

g. The Effects of Starvation on Acid Tolerance of Young-of-the-Year Smallmouth Bass

The effects of starvation on acid tolerance of smallmouth bass were investigated in the laboratory. Juvenile smallmouth bass were held under simulated winter conditions for up to five months. During these winter periods, losses in ash-free weight reached 30%, however, consecutive tests failed to demonstrate any decline in the short-term (less than or equal to seven days) tolerance of these fish for pH levels in the range from 3.0 to 4.5. The effects of calcium concentration, sodium concentration and fish body size (fork length) on tolerance of these pH levels were also examined. All three factors were positively related to pH tolerance. Over the pH range 3.0 to 4.0, where significant numbers of deaths occurred during the seven day experiments: doubling fork length increased time to death at any pH by 100%; at pH 3.0, doubling calcium concentration increased time to death by 13%; at pH 4.0, a 50% increase was observed; over the pH range 3.75 to 4.0, doubling sodium concentration increased time to death by 8%. These results support the conclusion that most northern smallmouth bass populations are unlikely to suffer significant over-winter deterioration in their ability to tolerate very low pH levels. Since fish body size has a strong influence on acid tolerance, it should be carefully controlled in future tolerance experiments.

h. Survival, Growth and Body Burdens of Metals in Stocked Lake Trout in Acidic Lakes in the Sudbury Area

Juvenile, hatchery-reared lake trout were stocked in about 20 Sudbury area lakes to assess the effect of lake acidity on survival and growth of stocked lake trout. Little or no survival of stocked fish occurred in lakes with pH less than 5.0. High survival and growth occurred in intermediately acidic (pH 5.6 - 6.1) and circumneutral lakes. The muscle tissue of recaptured trout did not contain unusually high levels of smelter metals (ie. copper, iron, nickel) or of acidification related metals (aluminum, manganese, zinc) compared with levels in fish from lakes farther from Sudbury. Only mercury showed evidence of bioaccumulation, but accumulation rates appeared to be lower than in many other parts of Ontario. Metal bioaccumulation was, therefore, not considered a concern for the rehabilitation of fish populations in Sudbury area lakes through hatchery stocking.

i. Reproduction of Brook Trout in an Acidic Stream

Spawning time and location were determined for a natural population of brook trout in the Chikanishing River (pH 5.7), a small river in Killarney Park. Brook trout spawned at a groundwater upwelling site (pH 6.7). During the first week of April, stream water pH declined to 5.2. Emergence from the redds began during the period of the acid pulse and continued until the pulse had passed. Toxicity tests were conducted in five lakes with a pH range of 4.84 - 5.64. Lethal pH thresholds for eggs, hatching embryos and free embryos were 5.1, 5.0, and 5.0, respectively. Estimated lethal thresholds for aluminum for the three early life stages varied from 0.20 - 0.25 mg·L⁻¹. Periodic swimming surveys during the winter revealed that adult brook trout overwintered

in high pH water in deep pools below the ground-water recharge zone. The field studies to confirm the timing of emergence relative to pH depressions are continuing.

j. Aurora Trout Reproduction and Rehabilitation

Historically, four lakes in the Temagami District were populated by aurora trout, but became too acidic to sustain the fish. Studies are underway to assess effects of acidic ambient conditions on survival and reproduction of reintroduced aurora trout.

Acclimation procedures were used to successfully reintroduce aurora trout into one of their native lakes. Hatchery reared fish were held for five days in an intermediately acidic lake (George Lake, pH 5.8). Surviving fish (54%) were then transferred to one of the aurora lakes (Whirligig Lake, pH 4.8) and held for 72 hours during which time no mortality occurred. Unacclimated fish experienced 82% mortality during 146 hours in the acidic lake. The growth and survival of these and earlier plantings of fish will be studied to determine if aurora trout will reproduce under the acidic conditions present in the native lakes.

MNR Wildlife Studies

a. Effects of Organics, Inorganics and Acidity on the Survival and Distribution of Amphibians

The distribution of amphibians in relation to pond chemistry was investigated near Sudbury, Ontario. Amphibian presence was documented in 118 breeding sites while 39 ponds were chemically analysed. Results show that the leopard frog (Rana pipiens), the green frog (R. clamitans) and the spring peeper (Hyla crucifer) are adversely affected by changes in buffering status (alkalinity, pH, etc.) (Fig. 24). The American toad (Bufo

americana), the green frog and the spring peeper are adversely affected by metals and other ions associated with acidic deposition.

This study also found high aluminum levels in ponds in the Sudbury region. These levels were the highest recorded in Ontario to date and were accompanied by the almost complete absence of the spotted salamander (Ambystoma maculatum).

Studies were initiated to further investigate the impact of acidification and aluminum on amphibians in the Sudbury area. The response of different life stages of the leopard frog (Rana pipiens) to a wide range of pH (4.6 - 6.5) and aluminum concentrations (0 - 1,000 $\mu\text{g}\cdot\text{L}^{-1}$) was studied. In embryos and newly-hatched tadpoles aluminum ameliorated the toxic effects of low pH (4.2 - 4.4) while becoming extremely toxic at higher pH (4.6 - 4.8). Embryos were most sensitive to low pH while tadpoles were much less sensitive to lowered pH and elevated aluminum. A second laboratory-based study conducted in 1987 looked at the influence of naturally occurring organic compounds on the survival of amphibian embryos and larvae in acidic aluminum or copper contaminated water. At low pH (4.2) aluminum ameliorated acid toxicity while at higher pH (4.5 - 4.8) the

organic compounds complexed a large percentage of the aluminum and caused a two-fold increase in the LC_{50} for aluminum. Comparisons between laboratory tests and surveys of pond chemistry suggest that:

1. aluminum and copper are not toxic to amphibians in ponds containing even low levels of dissolved organic compounds and
2. the organic compounds are probably toxic to amphibians in low pH, dark water ponds.

The survival of transplanted embryos and tadpoles of the wood frog (Rana sylvatica), the American toad (Bufo americanus), and the spotted salamander (Ambystoma maculatum) was studied in 16 concentrations of aluminum, and dissolved organic compounds. Mortality was associated with low pH and was directly attributable to high concentrations of dissolved organic compounds which were toxic only in acidic ponds (pH less than 4.5). Aluminum was only toxic in one pond which had extremely high concentrations (greater than 1,000 $\mu\text{g}\cdot\text{L}^{-1}$). In several other ponds, the concentrations of aluminum were theoretically high enough to kill the embryos or tadpoles (greater than 300 $\mu\text{g}\cdot\text{L}^{-1}$) but complexation by organic compounds may have reduced its toxicity.

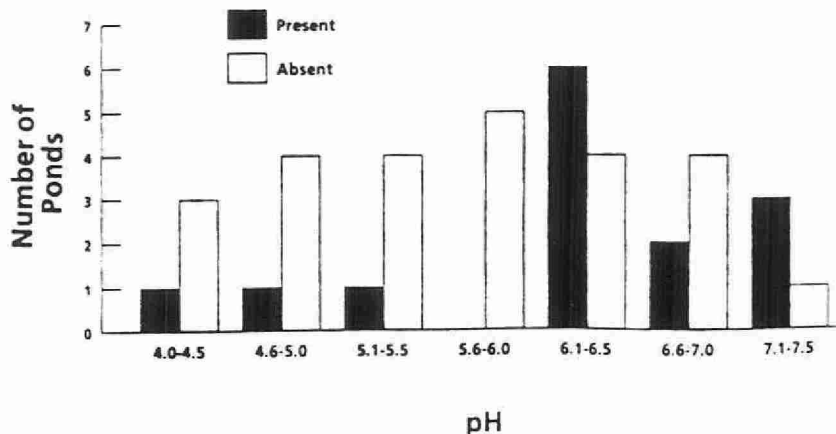


Figure 24: Presence of leopard frog Rana pipiens in relation to pond pH. This species was found in few low pH ponds; Hyla crucifer and Rana clamitans exhibited similar relationships.

b. Cadmium Burdens in Waterfowl

This program was established to determine the level of cadmium and its distribution in the common goldeneye. Cadmium levels in different age and sex classes of waterfowl, and measurements of cadmium levels in feathers as a reliable non-fatal field sampling technique for waterfowl are also being assessed. Implications of ingestion of these waterfowl by humans and animal predators will be examined.

Results to date have shown feather cadmium levels higher by a factor of ten than those reported in other published studies. A significant difference at variance with most published findings was also noted between sexes for the mean cadmium level in primary feathers. Continuation of these studies will correlate cadmium feather levels in goldeneye and other species to internal body burdens of this metal.

c. The Ontario Lakes Loon Survey

This program, undertaken in cooperation with the Ontario Region, CWS continues to investigate trends in the reproductive success of common loons (*Gavia immer*) in Ontario through volunteer surveys. More volunteers and acid-sensitive lakes will be added to the survey and methods of data collection and storage will be improved.

Preliminary results indicated that additional surveys of acidic lakes are required before the relationship between common loon reproductive success and acid sensitivity can be determined. An additional study undertaken with the Long Point Bird Observatory will investigate the mechanisms in the aquatic food chain which might affect loon chick survival.

C. REMEDIAL METHODOLOGIES
DEVELOPMENT

Recognizing that lake neutralization is at best a temporary measure to delay or reverse the effects of acidification, Ontario is continuing to develop lake neutralization expertise as a method of protecting and rehabilitating lakes. Technical study reports, a summary report, and a series of scientific papers have been prepared, detailing the findings from the first phase of the Experimental Neutralization Study, which began in 1982. Under a five year followup study commissioned in 1986, long-term trends in Bowland Lake and Trout Lake (neutralized in 1983 and 1984 respectively) are being monitored. Even under the most optimistic of emission-abatement scenarios, the significant reduction of acid inputs into many of Ontario's lakes is several years away. Lake liming may prove to be a feasible interim measure for the protection of important gene pools, or the rehabilitation of significant sport fisheries.

Bowland Lake

After neutralization, the pH of Bowland Lake increased from 4.9 to 6.7 and the alkalinity increased from $-0.3 \text{ mg}\cdot\text{L}^{-1}$ to $4.5 \text{ mg}\cdot\text{L}^{-1}$. Total aluminum decreased gradually from 130 to $30 \text{ ug}\cdot\text{L}^{-1}$.

Neutralization successfully improved water quality in Bowland Lake for biota and provided a suitable environment for lake trout spawning and successful hatching of eggs. While lake trout growth rates were initially high after neutralization, they subsequently declined when 200 additional fish were added to the lake. This may have been related to competition for a limited food base.

Other communities in the lake showed changes in species abundance and biomass but overall, did not appear to be negatively affected.

The phytoplankton community shifted from Rhabdoderma, a blue-green algae, to a community dominated by several other species more representative of a non-acidic system. Benthic algal abundance decreased after neutralization but eventually returned to pre-neutralization values. Species composition changed to reflect a community undergoing acidification stress in contrast to the original acidophilic community.

Changes due to neutralization in zoobenthos and zooplankton communities were primarily taxonomic, shifting to taxa more representative of non-acidic conditions, e.g. a decreased abundance of the acidophilic rotifer Keratella taurocephala.

Quantitative changes in zoobenthos (reduced biomass and mean size of zoobenthos) and zooplankton (reduced crustacean plankton biomass coinciding with increased rotifer and ciliate biomass, and increased abundance of Chaoborus punctipennis, appeared to be related to altered competitive and predatory interactions that may not be directly linked to lake neutralization.

Metal analysis of fish showed increased concentrations of mercury compared to pre-neutralization levels; however, concentrations remained low relative to human consumption guidelines and returned to pre-neutralization values the next year. Mercury increases are likely due to natural annual variations.

Between August 1983 and March 1986 the whole-lake pH, calcium and alkalinity of Bowland Lake decreased. About 40% of the added alkalinity was lost (Fig. 25).

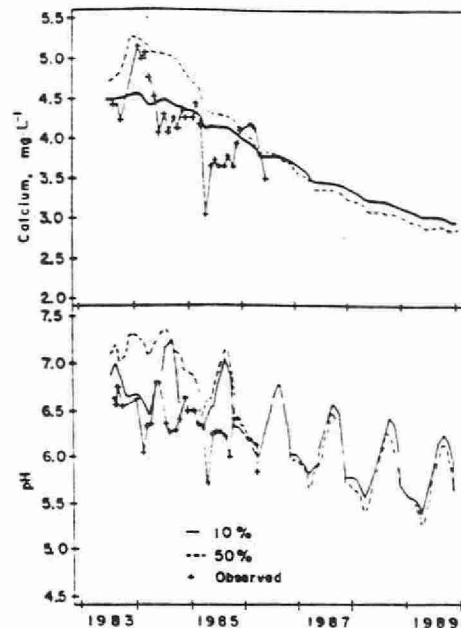


Figure 25: Predicted and observed reacidification of Bowland Lake. Observed pH and calcium concentrations are compared to model predictions using the assumption that settled calcium covered 10% and 50% of the lake bottom.

Trout Lake

In this low alkalinity lake, whole-lake neutralization successfully raised pH and alkalinity. The pH increased from 5.8 to 6.6 and alkalinity increased from 1 to 4 $\text{mg}\cdot\text{L}^{-1}$. Aluminum concentrations remained relatively unchanged at 30 - 35 $\text{ug}\cdot\text{L}^{-1}$.

While long-term studies are not yet complete, the short-term experiments showed that whole-lake neutralization provides additional protection against acidification, without adversely affecting the ecological community of the lake, including a lake trout fishery. It is premature to speculate on the long-term response of the lake trout to neutralization since fish spawned after neutralization will not enter the fishery until 1988.

After neutralization there was a decrease in abundance of the rotifer *Keratella taurocephala* while the mysid population increased. Based on preliminary examination of the data, major changes in the phytoplankton community were not evident.

Whole-lake pH, calcium and alkalinity of Trout Lake decreased between 1984 and 1986. About 25% of the alkalinity added was lost within 18 months (Fig. 26).

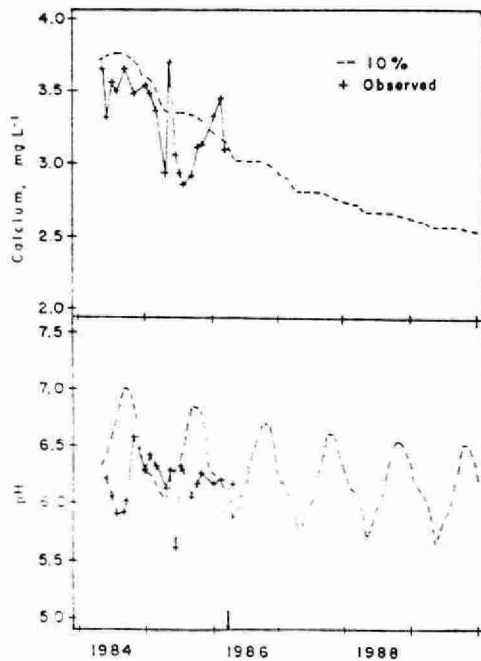


Figure 26: Predicted and observed reacidification of Trout Lake. Observed pH and calcium concentrations are compared to model predictions using the assumption that settled calcite covered 10% of the lake bottom.

Liming of Spawning Shoals

Preliminary experiments investigated the feasibility of treating lake trout spawning shoals with crushed limestone. In acidic Laundrie Lake, near Sudbury, incubation of lake trout eggs/sac-fry within plots of natural and limestone rubble showed improved survival in the limestone plots. Supporting behavioural studies in non-acidic Miskokway Lake, near Parry Sound, indicated that spawning lake trout do not avoid natural shoals artificially covered with limestone. Expanded studies are in progress on George and Johnnie lakes, near Killarney, to more thoroughly assess mortality and water chemistry.

On the basis of the positive results to date, site-specific shoal liming offers considerable promise as a mitigative technique - both as an additional protective measure in conjunction with whole-lake liming, or as the sole measure required in lakes where water quality problems occur only during spring runoff. An obvious advantage of shoal liming is its much reduced scale, and lower cost in comparison to whole-lake neutralization. Potentially, shoal treatments may also exhibit longer duration than whole-lake applications.

Completion of these studies should identify the feasibility and expected benefits of shoal liming as a mitigative technique for Ontario lakes.

ENVIRONMENTAL MANAGEMENT AND ECONOMICS

A. DAMAGE AND BENEFITS

Various Work Groups attempted to identify the biophysical data and dose-response relationships that are needed to estimate the actual and potential economic damages being caused by acid deposition and the benefits of control programs.

Discussions were held with various authorities on materials and structures effects of acidic deposition. Based on a review of the literature and other completed work, key data gaps exist for inventories of materials, buildings and structures that are exposed to acidic deposition. Further modelling effects were needed to generate estimates of the physical corrosion or damage that might be occurring due to acid deposition as well as estimate of monetary value surrogates of these effects (e.g. value of replacement of materials).

B. COSTS OF ABATEMENT AND MITIGATION

Reports on compliance by the four (4) major Ontario SO₂ emitters (Ontario Hydro, Inco Limited, Falconbridge and Algoma Steel) were reviewed for cost estimates.

Three investigations concerning acid deposition precursor abatement were initiated in fiscal year 1987-88. These studies include:

1. A review of SO₂ and NO_x control strategies to ensure that Ontario will achieve the 1993 reductions.
2. A Nitrogen Oxide and Volatile Organic Compounds Abatement Cost Study.
3. An assessment of the Cost Effectiveness of Mobile Source Pollution Control Systems.

C. EMISSIONS MANAGEMENT

Discussions between various federal and provincial agencies produced the principles for industrial participation in the sulphur dioxide emissions reduction program which flows from the Canada/Ontario agreement. Informal contacts with industry confirmed its agreement that the principles provide a solid foundation from which to negotiate the specific tripartite agreements.

In accordance with the Canada/Ontario agreement, Ontario reported on the progress of Countdown Acid Rain.

An independent review was commissioned to document and evaluate the methodologies the Countdown companies use to develop their acid gas emission numbers. The reviewers are also to recommend how the Ministry might verify the accuracy of emissions reported under Countdown Acid Rain.

PUBLIC AWARENESS ACTIVITIES

The Communications Work Group (with representatives from the Ministries of Intergovernmental Affairs, Tourism and Recreation, and Natural Resources), reviewed new strategies to increase awareness about acid rain among Ontario and American citizens.

A revised communications strategy directed toward targeted U.S. audiences stresses several themes:

- ° Commonality and Self-Interest: Acid rain is a continental problem and all North Americans have a stake in effective solutions.
- ° Out of the Trenches: Instead of focusing on the stalemate between those in the northeastern and midwestern states, people in other regions of the U.S. are being made aware of their stake in the issue. This goes beyond surface water acidification into possible terrestrial and health effects.
- ° Control Technology: Emission control technology does exist and can be implemented by industry and/or government.
- ° Economics: There are economic benefits to be reaped from abatement.
- ° Ontario's Success: Countdown Acid Rain serves as a model of a successful abatement program.

The new approach is intended to stimulate Americans to pressure their national government for acid

gas controls. To this end, several initiatives were undertaken in the U.S. and included the following:

- The Ministry of the Environment and Trout Unlimited jointly organized a mail-out of Ontario and federal government acid rain information pamphlets to Trout Unlimited members (43,000). The mail out was arranged for July 1988. Trout Unlimited has reported that it will continue to prompt its members to write their government representatives as new acid rain control bills enter Congress. This joint program evolved from a contact made at Trout Unlimited's 28th National Convention (August 1987), attended by APIOS representatives.
- Similar to last year, an acid rain display was exhibited and staffed by Ministry personnel at several international conferences and shows: The Globescope Conference in Idaho; The Harrisburg, Pennsylvania Sportsman Show (attended by approximately 700,000 people over its 11-day run); The Colorado Sportsman Show in Denver; and The National Wildlife Federation Annual Meeting in New Orleans. The display was well received at all four shows and many fruitful contacts were cultivated.
- Valuable contacts were also made at several conferences where Ministry personnel distributed acid rain information: Vote Environment, a Presidential Candidates Round Table Forum in New Hampshire; Restoring the Earth Conference in California;

and the National Association of Counties' Annual Meeting in Washington, D.C.

- Non-resident angling license: A tear-off card requesting information on acid rain was provided with the application form for all non-resident angling licenses. Approximately 10,000 people responded by returning their cards to the APIOS Office and subsequently received an information package. In this way, an important audience was informed about the environmental effects of acidic deposition. This project will be repeated in the 88-89 fiscal year.

LABORATORY SUPPORT SERVICES

Laboratory support for the diversified analytical needs of the scientific work groups within APIOS is provided by various analytical units of the Inorganic Trace Contaminants and Water Quality Sections, and the Trace Organic Section of the Toronto laboratory, in addition to a water and soils laboratory in Dorset.

A summary of the total test load for the program is shown in Fig. 27. Details of the test load by task for 87/88 is given in Table 3.

The challenge of providing analytical support for a major program such as the Acid Precipitation in Ontario Study has resulted in many analytical advances. These are summarized in Table 4.

HIGHLIGHTS FOR 1987/88

Two more Dorset workstations were put on direct computer input:

1. DOALSP (aluminum speciation via catechol violet colorimetry) and
 2. DOT (alkalinity titration)
- bringing the number to four, representing 56% of the Dorset water lab test load.

The Dorset soils lab continued to support a variety of studies: Hardwood Decline; Soil Baseline; Biogeochemistry; and Exclusion Canopy.

Special analyses for the Biogeochemistry Study included silica analysis on ammonium oxalate soil extractions, and sodium-pyrophosphate extractable iron and aluminum on field moist soils. Investigation began on the

comparison between the current 2N NaCl extraction for exchangeable cations, and a BaCl₂ extraction, a simpler procedure subject to fewer interferences during analysis.

New laboratory equipment was commissioned in Dorset to do:

1. Carbonate-C in soils measured with a new Coulometrics carbonate-C analyzer;
2. Anion analysis for the weathering study using a new dionex ion chromatograph; and
3. Measurements of carbon dioxide in water samples using a new Varian gas chromatograph. A second polarographic analyzer with a dual disc rotating glassy carbon electrode system will be used to increase productivity in the ultra-trace level metals work.

An intercomparison of sequential air filters used in the precipitation APIOS and AES networks showed nylon pre-filters and the teflon nitric acid filters were acceptable. While there were problems in the analysis of the impregnated SO₂ W41 filter extracts further work is planned to confirm the comparison data and both agencies will carry out on-going intercomparisons over the two year Eulerian model field verification study.

Also related to the field verification study is the analysis of ammonia on citric acid

impregnated filters extracts. An AES intercomparison of the ion chromatography versus standard colorimetric methods showed that the colorimetric method suffers from severe matrix problems and analysis by ion chromatography is preferred. Since MOE does not have method in

place for ammonia by ion chromatography, and the test load is low (approximately 30 samples a month for the duration of the study), AES agreed to analyze all citric acid filter extracts for both agencies.

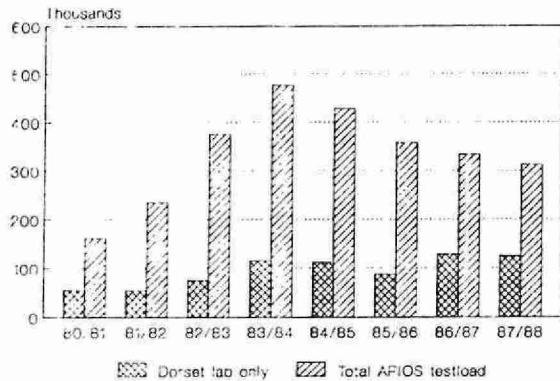


Figure 27: Laboratory workload.

Table 3: APIOS Tasks Supported by Laboratory Services Branch in 87/88

Study	Number of tests
Atmospheric	86,200
Aquatic	142,900
Terrestrial	23,000
Biogeochemical	62,100

Table 4: Laboratory Research and Development in Support of APIOS

- Developed automated acidity titrator.
- Designed and implemented Gran titration.
- Developed ion chromatography for anions.
- Established filter extraction methodology.
- Implemented low level cation analysis by AAS.
- Developed ICP for trace metal analysis.
- Established low level DIC colorimetry.
- Developed aluminum speciation methodology.
- Established ASV techniques for metals.
- Established "clean room" techniques.
- Established a dedicated soils lab.
- Developed/modified numerous soils methods.
- Developing gas chromatography for CO₂.
- Developed organic precipitation sampling method.

APPENDIX I

INTERNATIONAL LRTAP PROJECTS - MOE CO-FUNDING

<u>Project Title</u>	<u>Funding Agencies</u>	<u>Purpose</u>
Acid Deposition and Oxidants Model (ADOM)	Environment Ontario Atmospheric Environment Service Umweltbundesamt (West Germany) Environment Quebec State of Minnesota State of New York Electric Power Research Institute	To improve predictions of source/receptor relationships, through the use of eulerian concepts.
Bilateral Hardwood Decline Study	Environment Ontario Ministry of Natural Resources Environment Canada Department of Natural Resources - New Brunswick Ministry of Energy and Resources - Quebec Northeast Forest Cooperative	A study of the etiology of sugar maple decline across northeastern North America using a common methodology.
Dry Deposition Intercomparison Measurements	Environment Ontario Atmospheric Environment Service Illinois State Water Survey Nation Aeronautical Establishment U.S. Department of the Interior National Oceanic and Atmospheric Administration Environmental Protection Agency Argonne National Laboratory Oregon State University	To improve quality control and comparability of Canada/U.S. results.

<u>Project Title</u>	<u>Funding Agencies</u>	<u>Purpose</u>
Eulerian Model Field Verification	Environment Ontario Environment Canada U.S. E.P.A. Electric Power Research Institute	A study design has been prepared for the field verification of the eulerian model.
Rain Acidity Interlaboratory Study of Damage to Agricultural Crops	Environment Ontario Boyce Thompson Institute Argonne International Laboratory Corvallis Environmental Research Laboratory Oakridge National Laboratory Brookhaven National Laboratory	To measure the effects of different pH's on crops and to standardize techniques and procedures. Study has been completed. A similar study is being developed for exclusion canopy work.
Reversing Acidification in Norway - NIVA	Environment Ontario Norway Sweden Environment Canada United Kingdom	To test hypotheses on watershed sensitivity and to measure watershed response to reductions and increases in acid loadings. This issue has been recently raised by the U.S. E.P.A. as an impediment to designing a control program.
Unified Acid Deposition Data Base for Eastern North America	Environment Ontario Environment Canada National Atmospheric Deposition Program, U.S. Geological Survey Battelle Pacific Northwest Laboratory, U.S.	The unified data base should be useful for mathematical model evaluation and historical trend analysis.

INTERNATIONAL LRTAP PROJECTS - MOE PARTICIPATION

<u>Project Title</u>	<u>Participating Agencies</u>	<u>Purpose</u>
Aluminum Biogeochemistry in Forested Watersheds	Electric Power Research Institute Environment Ontario Environment Canada United States West Germany Norway Sweden United Kingdom	To identify and quantify the release, transport and toxicity of aqueous aluminum in the natural environment. Aluminum is toxic to both fish and trees.
BACG (Bilateral Advisory Consultative Group)	Environment Ontario Ministry of Energy Ministry of External Affairs Environment Quebec Environment Canada Office of the President Department of State, U.S. Department of Energy, U.S. U.S. EPA National Acidic Precipitation Assessment Program	To respond to or implement recommendations of the Special Envoys' Report
CAPTEX Data Analysis and Model Comparisons	Environment Ontario Environment Canada National Oceanic and Atmospheric Administration, U.S. Department of Energy, U.S.	A workshop on the Cross Apalachian Tracer Experiment (CAPTEX) was held November, 1985 to compare model predictions with ground-level tracer concentrations.
Free Aluminum in Surface Waters	Environment Ontario University of Maine	Agreement for interchange of samples for analysis to determine compatability of the methodologies.

<u>Project Title</u>	<u>Participating Agencies</u>	<u>Purpose</u>
Fisheries Loss Assessment Program	NAPAP Environment Ontario Ontario Ministry of Natural Resources EPRI Environment Canada	To assist NAPAP in the design of a program to assess fisheries loss in the U.S. related to acidic deposition.
Human Health Effects Related to Aquatic Effects of Acid Deposition	EPA Environment Ontario Various State Health Agencies	MOE has been invited to sit on a Committee of experts to determine the exact nature and extent of these human health effects.
Informal Calibrated Watershed Modelling Group	Environment Ontario Environment Canada United States Norway Sweden	To compare results and ideas on watershed studies. The work defines effects of acid rain and develops target loadings to prevent damage.
Interlaboratory Quality Assurance	Government and private laboratories in Canada and the U.S. (over 50 labs involved, including MOE)	To ensure the validity and compatibility of all data collected under LRT programs in North America.
Lake Acidification Mitigation Program	EPRI Clarkson College Environment Ontario	MOE has been requested to provide advice and information concerning lake liming projects.
National Acidic Precipitation Assessment Program Review	Environment Ontario Environment Canada Fisheries and Oceans Canadian Forestry Service Government and private laboratories in U.S.	Review of NAPAP interim assessment document findings.

<u>Project Title</u>	<u>Participating Agencies</u>	<u>Purpose</u>
National Surface Water Survey	EPA Environment Ontario Environment Canada	To characterize current water chemistry of lakes and streams in five U.S. Regions. MOE has been requested to assist in the development of the survey design.
Ontario/Germany Memorandum of Understanding	Ontario Federal Republic of Germany	To exchange information, scientists and modelling results to ensure that similar methodologies are used so that final results may be compared.
Ontario/Michigan Memorandum of Understanding	Ontario Michigan	To exchange information and perform joint studies to achieve and maintain a quality of environment to protect human health and the ecosystem where activities of one jurisdiction may affect the environment of the other.
Ontario/Minnesota Memorandum of Understanding	Ontario Minnesota	To exchange information on acid rain; to cooperate on specific projects (atmospheric modelling, RAIN - NIVA, aquatic effects in a medium deposition area).
Ontario/New York Memorandum of Understanding	Ontario New York	To exchange information on acid rain to improve understanding of acidification of the environment and establish coordinated courses of action in order to encourage abatement measures on an international basis.
Ontario/NADP Intercomparison Study - Ely, Minnesota	Ontario National Atmospheric Deposition Program	To improve comparability of data.

APPENDIX II

A.P.I.O.S. RELATED TECHNICAL REPORTS AND SUBMISSIONS

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